1969

Physical and economic factors associated with the establishment of stream water quality standards

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70-13,581

DOUGAL, Merwin Dean, 1928-
PHYSICAL AND ECONOMIC FACTORS ASSOCIATED WITH THE ESTABLISHMENT OF STREAM WATER QUALITY STANDARDS. (VOLUMES I-III).

Iowa State University, Ph.D., 1969
Engineering, sanitary and municipal

University Microfilms, Inc., Ann Arbor, Michigan

PHYSICAL AND ECONOMIC FACTORS ASSOCIATED WITH THE ESTABLISHMENT OF STREAM WATER QUALITY STANDARDS

by

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VOLUME I of III

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Major Subject: Sanitary Engineering

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

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Signature was redacted for privacy.

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1969

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A STUDY IN THREE VOLUMES

PREFACE

The stream system in a river basin is an integral part of man's total environment. Its natural function is to return water to the ocean, the ultimate sink for all of the earth's residues as well as being the basic source of atmospheric moisture. The stream system serves also as a natural habitat for various flora and fauna which contribute to a healthy, productive aquatic environment. Man's activities in the twentieth century period of industrialization have accelerated the degradation of the water environment. Serious conflicts related to water quality have arisen among the groups making beneficial use of the surface water resource. Concern at all levels of government has resulted in increased attention and action directed toward the solution of water pollution problems.

Recent research in water quality has been replete in all three dimensions of the water quality framework — the technical, the economic and the institutional. Problem areas such as public health, resources use, technical innovations, economic alternatives, social aspects, and political-institutional-management relationships have been identified and studied through research endeavors. One of the principal objectives of current research is the development of methods of obtaining an optimal level of water quality in a stream commensurate with man's desired uses and the relevant economic constraints. A corollary objective

is determining the most economical solution for treating a region's wastes to obtain a desired minimum level of stream water quality, allocating specific treatment plant efficiencies among the several water use groups competing for the convenience of the stream's water conveyance mechanism.

In a study confined within a single dimension of the threefold technical-economic-institutional framework, it is likely that concepts and data from the other dimensions are lacking. This frequently results in the introduction of over-simplifying assumptions. A comprehensive study of methods for achieving selected water quality objectives should include the necessary elements of all three dimensions. Several case studies of selected river basins have been made recently to illustrate the application of newer methods of technical and economic analyses. However, no comprehensive studies encompassing these three dimensions have been made for Iowa, and the status of the interrelated elements has not been explored fully in this region.

This treatise is devoted also to the water pollution problem, with specific emphasis on problems in Iowa. Adoption and enforcement of the Iowa water quality standards for surface waters have as their objective the enhancement of water quality. The degree to which this enhancement can be realized and the related economic impact of such enhancement has received major attention in this study. The purposes for which this detailed study was conducted include

- to explore in a broad manner the underlying principles of each of the three dimensions (technical-economic-institutional) as they relate to stream water quality standards in Iowa,

- to list and evaluate the parameters that will influence water quality in Iowa streams including those that are of greatest concern in the establishment and enforcement of stream standards,
- to review and evaluate the hydrologic characteristics of Iowa streams as these characteristics become determinants in the water quality enhancement program,
- to identify the nature and characteristics of municipal effluents discharged to the stream environment,
- to study the response of a typical central Iowa stream as it receives waste discharges from a municipal water pollution control plant, and
- to determine for an urban area the economic importance of water pollution control and stream water quality enhancement, and the related impact of water quality standards on expenditures for a stream improvement program.

This treatise on water quality is divided into three parts. Vol. I is devoted to the initial two purposes listed above, and includes (1) a historical review of the water pollution problem, (2) identification and discussion of the potential effects of pollutants, and (3) application concepts for establishment and enforcement of water quality standards. Vol. II is devoted to a detailed study of Iowa stream conditions as outlined in the last four of the six purposes listed above. These specific studies include (1) a general study of Iowa stream water quality problems and availability of data, (2) the relationship of hydrologic characteristics and assimilative capacities of Iowa streams, and (3) a comprehensive technical-economic case study of the Skunk River at Ames, Iowa. Vol. III consists of the appendices for the detailed studies, and includes (1) basic data for the study, (2) selected hydrologic and water quality study information and results, (3) tabulated results of the water quality response model for the study area, and

(4) other supporting data.

It was the goal of this research endeavor to compile in one document the pertinent information concerning water quality in surface waters, and to provide through the comprehensive case study a means of directing future research efforts and activities. These are outlined in the concluding section of Vol. II. The case study permitted observing and measuring the response of the stream environment to man's water quality inputs, provided an opportunity for concentrated research and application methods, and hopefully produced meaningful results for a river basin in central Iowa where a rapidly expanding urban area is located.

A PHILOSOPHY FOR THE WATER QUALITY ENHANCEMENT PROGRAM

As applied to the increased pollution of our water resources, the need for reasonable water quality standards for surface waters, and efforts to implement improved water pollution control measures:

> "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it."
>
> Max Planck

I. INTRODUCTION

A. General

The stream system in a river basin plays an integral role in the hydrologic cycle. In the transfer of moisture from the sea to the land and thence back again to the sea, the stream system serves as the conveyance mechanism for the return flow of water at the surface of the earth. However, only a relatively small fraction of the annual precipitation falling upon the land surface returns to the ocean as streamflow. In the United States, this amounts to about 9 in. of the 30 in. of average annual precipitation. Regional variations of this fraction range from less than one-tenth in semi-arid areas to about one-half in mountainous areas where orographic precipitation is a principal factor in contributing to large volumes of runoff (Linsley et al., 1949; U.S. Senate Select Committee, 1959a, 1960a). This amount of runoff, although a small portion of the total annual precipitation, is sufficient to carve out the valleys, reshape the alluvial flood plains, and at the same time provide a readily available source of water for beneficial use by man. Because man's use of the stream system is an artificial or manmade use superimposed on the natural system, a review of the physical characteristic of the stream system serves as a logical starting point in a stream water quality study.

B. Natural Sources of Streamflow

The hydrologic cycle under natural conditions produces four sources of supply to the water in a stream (Linsley et al., 1949, 1958; Chow, 1964). The most obvious source is direct precipitation, where rain or snow falls directly on the stream surface. A second source is direct surface runoff, the portion of precipitation arriving at the stream by the way of overland flow across the earth's surface. Floods are the immediate consequence of excessive amounts of direct surface runoff. A third source, interflow or subsurface flow, derives from the movement of water laterally beneath the earth's surface following surface infiltration. The existence of interflow requires a relatively impermeable stratum in the subsoil which prevents downward percolation, and under the influence of gravity the water moves laterally at shallow depths toward the stream channel. Interflow has been identified principally in forested mountainous regions, and its presence was studied in detail at the Coweeta Hydrologic Laboratory in western North Carolina (Hursh and Brater, 1941; Wisler and Brater, 1949). The fourth source is groundwater, which usually supplies water to the stream at a relatively slow rate through the process of infiltration, percolation, and seepage discharge. None of the four sources is necessarily independent of the others and moisture falling as precipitation may be conveyed from one source to another before appearing as streamflow at some point in the stream system.

Although the moisture being evaporated and transferred landward from the ocean or being evaporated from the surface of the land is essentially pure, this identical idealistic quality cannot be conferred upon the water in a stream. Purity is lost initially as precipitation carries earthward a variety of particulate matter from the atmosphere, some natural and some introduced by man. In the hydrosphere, water has the inherent ability to dissolve many minerals and organic substances, and in motion it has the additional ability to erode and carry particulate matter in suspension (U.S. Senate Select Committee, 1960e; Chow, 1964). Because water is essential to the life cycle of plants and animals, the stream system also becomes an ecological system, an "ecosystem" for an aquatic environment (Leopold, 1960; Klein, 1962, p. 316; Ruttner, 1963; Ingram et al., 1966; National Academy of Sciences, 1966b, pp. 36-38). Therefore, under natural or manmade conditions, both the quantity and quality of water in a stream will be influenced by spatial and temporal variations in (1) the sources of supply, (2) the physiographic features and geological formations relating to each source, and (3) the ecological system of biological life existing in the stream.

C. General Effect of Man's Activities

The natural processes influencing the quantity and quality of streamflow can be altered significantly by man's activities. The water conveyance mechanism of the natural stream system serves as a useful and easily available base for many activities of a developing society, and is easily changed by a modern economic society. Among the beneficial uses which can be made of the water flowing in a natural stream system are: (1) water supply for various purposes, (2) power production, (3) navigation, (4) recreation, (5) fish and wildlife propagation, and (6) waste disposal, including discharge, dispersion, transport, and assimilation phases (Water Resources Policy Commission, 1950; U.S. Senate

Select Committee, 1959a, 1960a, 1960e). The quantity of streamflow can be changed by stream withdrawals, by storage and subsequent releases, or by effluent discharge following beneficial use of water withdrawn from one or more water sources, including groundwater. The combined effect may either increase or decrease the natural flow of the stream. Although improvement of the natural water quality may occur as a by-product of a beneficial use of water, more frequently deterioration results (U.S. Senate Select Committee, 1960e). Each beneficial use of water can contribute to the deterioration of water quality in the stream. In addition, changes in the water conveyance mechanism which are made frequently (in the form of extensive channel improvements, for example) may adversely affect the water quality in the stream.

Water use groups within our society frequently have used the water conveyance mechanism indiscriminately in efforts to improve their immediate economic well-being. Surface runoff from agricultural and urban lands is shunted quickly to natural or improved channels, with little or no concern for changes in the quantity or quality of the water. Water withdrawn from the stream for a beneficial use is frequently returned in a deteriorated condition which destroys a portion or all of the ecological system. Untreated wastes of all kinds are discharged conveniently to the water conveyance mechanism of a stream system, hopefully placing them "out of sight and out of mind." In the absence of intensive development of a stream system, perhaps this comfortable state of mind can be achieved, especially during the developing phases of a complex industrial society or in sparsely settled areas (Phelps, 1944, pp. 1-26; Pollution Control Council, 1961). Eventually, however, the adverse effects of pollution upon other members of society who are endeavoring to make subsequent beneficial use of the streamflow do not go unnoticed. Streamflow becomes a "scarce" economic resource in a competitive environment (Kneese, 1962; Timmons, 1967). Conflicts of use arise and some mechanism of solving the conflicts is sought.

This descriptive account of the general problems of maintaining water quality in a stream system illustrates two important facts. First, the natural quality of streamflow is in itself subject to considerable variability. Second, the water quality in a stream system can be altered easily by the numerous activities characteristic of a modern agricultural and industrial economy.

Conflicts of use, inequitable allocation of costs and benefits, and inadequate legal remedies have resulted from the competitive nature of water use. This has led in the last decade to an overwhelming concentration of attention to the stream water quality problem by the public and its elected representatives in local, state, and federal governments. Their considerations and deliberations through the political process have culminated in the nation-wide establishment of stream water quality standards in a massive effort to "enhance" the quality of the surface waters of the nation (U.S. Congress, 1965). State statutes with the same objective have been enacted, including one by the State of Iowa (1965). However, the magnitude of the improvement which can be achieved is limited by (1) the level of technology, (2) the economic relationships which exist between water use and water quality, and (3) structural or institutional factors (National Academy of Sciences, 1961; Timmons, 1967). All three dimensions of this water quality framework must be considered if governmental establishment of stream water quality standards is to meet the test of reasonableness and result in effective and real improvement of water quality.

D. Stream Water Quality Research and the Proposed Study

Recent research in water quality has been replete in all three dimensions of the water quality framework, i.e., technical, economic, and structural. Problem areas such as public health, resources use, technical innovations, economics, social aspects, and political-institutional-management relationships have been identified and studied through research endeavors (National Academy of Sciences, 1966a, 1966b). One of the principal objectives of current research is the development of methods of obtaining an optimal level of water quality in a stream commensurate with man's desired uses and the appropriate economic constraints (Kneese, 1962, 1964). A corollary objective is determining the most economical solution for treating a region's wastes to obtain a desired level of water quality, allocating specific water pollution control plant treatment efficiencies among the several water use groups competing for the convenience of the water conveyance mechanism of the stream system. In a study confined within a single dimension of the threefold technical-economic-institutional framework, it is inherent that concepts and data from the other dimensions may be lacking. This frequently results in the introduction of over-simplifying assumptions. A comprehensive study for achieving selected water quality objectives should include the necessary elements of all three dimensions. Several case studies of selected river basins have been made in recent years to illustrate the application of newer concepts and methods of technical and economic analyses (Thomann, 1965; Kneese, 1966; Davis, 1966; Johnson, 1967). However, no comprehensive studies encompassing these three dimensions have been made in Iowa, and the status of the interrelated physical, economic, and structural dimensions has not been explored fully in this region.

The primary purpose of this research program is to identify the nature of the water pollution problem in Iowa, to define the water quality parameters and relationships that will be of importance in research studies, and to outline problem areas toward which concentrated research efforts can be directed in the future. A case study of a central Iowa stream is selected as the principal method through which a relevant research program might be conducted.

An initial review of available stream data concerning water quality and the ability of Iowa streams to assimilate waste discharges indicated a paucity of data in this field. Only monthly water quality samples were being obtained at selected locations (Schliekelman, 1965), and occasional stream sanitary surveys made in short reaches where gross pollution was discovered. The available data were grossly inadequate for determining the physical and economic relationships related to the establishment of stream water quality standards. As a result of this discouraging search for existing data and knowledge about Iowa stream water quality, the initial scope of the study was broadened to include a review and analysis of hydrologic variables as related to water quality, a thorough study of the physical stream environment in the selected area, and a proposal to do additional hydraulic and water quality studies in the study area with economic evaluation being the concluding aspect of the overall study. This decision was made on the supposition that allocation of a certain amount of the nation's research talent should be devoted to gaining a better understanding of the stream environment and its response to the residues of man placed therein. The additional data collected and knowledge gained serve to make future economic analyses more meaningful.

This concept is in agreement with national recommendations, which have stated that too little is known today about the response of the natural environment to human activities. One of the five major recommendations of a waste management report (National Academy of Sciences, 1966a) to the Federal Council of Science and Technology was

> That there also be provided, within the structure of the federal government, a program including contract work, to support the following:
>
> a. A legal study on legislative precedents and needs, ...
>
> b. Biological and ecological studies.
>
> c. Engineering studies, including economic considerations, relating to residue management.
>
> d. All relevant studies toward closing the loop from resource to user to reuse as a resource.

The report concluded that streams, rivers, lakes, groundwater and estuaries have not yet been studied sufficiently, or sampled intensively enough, to permit making reliable predictions of the fate of pollutants in surface waters. Such inadequacy of knowledge of Iowa streams and lakes was noted in a water quality symposium held at Ames at the time this study was initiated (Maloney, 1967). Kneese (1962) has expressed similar concern over the inadequacies of present knowledge.

Since this study of stream behavior in Iowa respresents an initial but comprehensive analysis of the many interrelated factors, including the physical and economic, which may affect or be affected by the establishment of stream water quality standards in Iowa, it is divided into several phases. The first two phases are included in Vol. I. The initial phase consists of a comprehensive overview of the total water pollution problem and its many facets, as these are related to stream behavior and to the establishment of meaningful water quality standards. The second phase will be devoted to evaluation of the physical and economic mathematical models which have been developed to simulate the response of the stream environment to waste discharges, and of the economic impact of these discharges. Selection of an appropriate model for the study stream cannot be made a priori, but can only be accomplished ex post facto after completion of initial stream water quality studies that indicate which physical parameters and coefficients are important.

The remaining study phases are included in Vol. II. The third phase of this study involves the physical stream system and hydrologic behavior of Iowa streams, including the study stream area. The fourth phase includes an analysis of waste treatment methods used in Iowa and an experimental study of the characteristics of effluents from water pollution control plants representing the three major waste treatment processes used in Iowa. These are the trickling filter and activated sludge secondary treatment units, and the waste stabilization ponds. Stream studies to determine the response of the stream environment to the effluent discharged from a typical water pollution control plant are included in the fifth phase. This will be followed by the development of a mathematical model to simulate the observed response of the stream environment to both existing and future waste loads.

Evaluation of the economic implications of water pollution control in the study area at Ames, Iowa, is considered the final phase of this study. This will indicate to the public the cost of achieving pollution control and various desired levels of water quality in the receiving stream under future conditions, especially as the stress under population growth is reflected in the period 1965-2000.

II. A HISTORICAL REVIEW OF THE WATER POLLUTION PROBLEM

A. Defining the Nature of Pollution

The terminology prevalent in the field of water quality management will be defined and discussed as a preliminary step in the review of water quality and water pollution problems. What is meant by water quality? What constitutes pollution of a surface water? When is a surface water contaminated? What additional but meaningful terms appear in water quality discussions?

1. Water quality

Water quality is a general term that has been applied to the properties of water influencing its use (Hem, 1959; Timmons, 1967). Every beneficial use requires a certain level of water quality. Water always has a quality associated with its quantity, and quality should be expressed in terms of some essential property (Burke, 1966). These properties have also been called substances, classified as physical, chemical, biological, or radioactive, and quantitatively related to the beneficial uses of water (McKee and Wolf, 1963). These same properties were divided into four groups by Baumann (1967), according to whether their presence would be (1) not permissible, (2) undesirable or objectionable, (3) permissible but not necessarily desirable, and (4) desirable, as related to the subsequent use of the water.

These properties (or substances) must be identified and measured quantitatively in order to describe water quality, selecting those which can affect water's usefulness. Properties of water can be affected by both nature and man, and early investigations showed that frequent measurements, both temporally and spatially, were necessary for complete identification of the water's properties (Streeter and Phelps, 1925; Phelps, 1944). For instance, the temporal variations of water quality at a specific stream sampling location have been attributed to two important fluctuations: (1) waste discharges which were seldom constant throughout the day, and (2) the quantity of receiving water which was subject to temporal hydrologic changes (McKee and Wolf, 1963, p. 25). Identification of these many properties of water as "potential pollutants" (McKee and Wolf, 1963, p. 123) confirmed this unique influence of water use in selecting or designating water quality parameters or substances for which quantitative analyses were sought.

2. Pollution, contamination, nuisance, and natural degradation

Pollution and contamination are two terms appearing frequently in water quality literature, but they have been defined differently in various discussions and legal statutes. Webster's New Collegiate Dictionary (Merriam, 1967) differentiates between these two terms, first by stating that to contaminate is "to make unfit for use by introduction of unwholesomeness or undesirable elements." Contamination implies intrusion or contact with an outside source as the cause. The concept of pollution is stated as being "to make impure; to defile; to make physically impure or unclean." Pollution stresses the loss of purity and cleanliness through contamination.

This implication of contamination as a physical act which creates a state of pollution was substantiated further by the definition assigned to pollution in the Iowa water pollution control law (Iowa Code, 1966a). Pollution was defined as

> ...The contamination of any waters of the state so as to create a nuisance or render such waters unclean, noxious or impure so as to be actually harmful, detrimental or injurious to public health, safety or welfare, to domestic, commercial, industrial, agricultural or recreational use or to livestock, wild animals, birds, fish or other aquatic life.

Contamination was not defined in the law, nor was it again mentioned.

The two terms have been given a separate sense in other states, and a subtle distinction between the two has been introduced. In the field of sanitary engineering Fair and Geyer (1954) stated that contamination of a surface water was

> ...the introduction or release into it of potentially pathogenic organisms or of toxic substances that render the water hazardous and, therefore, unfit for human or domestic use.

Pollution of a surface water was stated to be

> ...the introduction into it of substances of such character and in such quantity that its natural quality is so altered as to impair its usefulness or render it offensive to the senses of sight, taste, or smell.

In this sense contamination might accompany pollution, and in a corollary sense pollution in general also implied potential contamination. Again, the reference to beneficial use should be noted. This latter implication, that contamination creates a hazardous condition precluding further use and that pollution is distinguishable from contamination and of lesser magnitude healthwise, was expressed in the California water law (California Water Code, 1959). Contamination was defined as

> ...an impairment of the quality of the water of the State by sewage or industrial waste to a degree

> which creates an actual hazard to public health through poisoning or through spread of disease.

Pollution was defined in the water code as

> ...an impairment of the quality of the waters of the State by sewage or industrial waste to a degree which does not create an actual hazard to public health but which does adversely and unreasonably affect such waters for domestic, industrial, agricultural, navigational, recreational, or other beneficial use, or which does adversely and unreasonably affect the ocean waters and bays of the State devoted to public recreation.

A nuisance category was established in the code and defined as

> ...damage to any community by odors or unsightliness resulting from unreasonable practices in the disposal of sewage or industrial waste.

This created a three-level differentiation of water quality, associated primarily with the problems of sewage and industrial wastes in California. However, Fair and Geyer (1954) included the nuisance or personal offensiveness category within the definition of pollution. In the Iowa law, all three were coalesced into the definition of pollution.

Various terms have been introduced to express the deterioration of water under natural conditions, as in a forested mountain watershed, for instance. Problems ranging from decomposition of wild animal carcasses lying in streams to overgrazing and accelerated land erosion from overpopulated game areas were reported in the Pacific Northwest (Pollution Control Council, 1961). The term "natural" pollution was applied to these problems by the Council (1961) and also by Timmons (1967). "Degradation" was the term selected by McKee and Wolf (1963) to separate deterioration occurring from natural causes from that occurring as a result of man's activities.

If all of these categories can be included, a four-level classification is obtained. Deterioration of water quality can be attributed to one of four conditions: (1) contamination, (2) pollution, (3) nuisance, or (4) natural degradation. Under this classification system, a stream survey would be required to ascertain if one or more conditions was responsible for water quality deterioration, thence permitting the precise status of the water quality to be determined.

Burke (1966), however, suggested the adoption of the singular term "water pollution" to avoid the necessity of multiple-term language in which precise classification of a specific surface water might be difficult to accomplish. Recognition was made of the fact that water always possesses a quality, and there are few waters which are not deteriorated to some extent. Burke then defined water pollution as

> ...the reduction in the quality of water to an extent that some beneficial use of the water is harmed.

This definition is similar to the definition adopted by the U.S. Senate Select Committee (1960e). Burke stated further that water becomes more polluted as its quality is reduced, and concluded that requirements for a legal definition can be resolved by writing standards to describe that level of quality below which the water is legally polluted.

This single concept of pollution was adopted recently in a comprehensive report on the entire field of waste management problems (National Academy of Sciences, 1966b). Pollutants were classified as the residues of the things society makes, uses, and throws away. Pollution, therefore, was stated to be a resource out of place, and it was recognized that substances causing pollution can be valuable materials under other circumstances. Pollution was defined in the report as

> ...an undesirable change in the physical, chemical, or biological characteristics of our air, land, and water that may or will harmfully affect human life or that of other desirable species, our industrial processes, living conditions, and cultural assets; or that may or will waste or deteriorate our raw material resources.

In this study, water pollution will be defined and used within the context of this singular definition, recognizing that classification within the four-term meaning can be made only after comprehensive water quality analyses are completed and a substantial body of knowledge is gained concerning the land, water, and other resources in a river basin.

3. Potential pollutants and other pollution terms

Not only can a vast number of substances be found in water, but their effects upon the beneficial uses of water can be equally vast in number. For this reason, the concept of "potential pollutant" was adopted by McKee and Wolf (1963). Each substance that may be found in water was deemed to be a potential pollutant. Potential was used to denote that, if concentrated sufficiently, the substance could adversely or unreasonably affect one or more beneficial uses of the water; but, if removed, treated, or diluted sufficiently, the substances would be harmless to all.

According to Gloyna (1966), pollutants should be divided into two categories, conservative and nonconservative. Conservative pollutants were considered to be relatively stable substances, not altered by the normal biological processes that occur in receiving waters. Common examples given were inorganic chemicals such as chlorides and metallic salts. Nonconservative pollutants were those that could be changed in character by the physical, chemical and biological forces that are exerted in a natural aquatic environment. Thus, a nonconservative pollutant would be assimilated in time by the ecological system present in the stream environment; it might disappear, or be converted in form. Organic compounds found in domestic sewage would fall into this category.

The term "corollary pollutant" was also introduced by McKee and Wolf (1963) to identify substances of natural origin which have a tendency to grow excessively and cause an impairment of water quality when excess nutrients are provided through the discharge of sewage and industrial wastes. Heavy algal and aquatic weed growths and their subsequent decay were given as typical examples.

Two additional terms are considered important in evaluating interrelationships between or among these substances found in water (McKee and Wolf, 1963, p. 26): "synergism" and "antagonism." Synergism implies that the total effect of discrete substances is greater than the sum of the separate effects taken independently. Antagonism implies the opposite, i.e., less effect. Increased toxicity to biological life from combinations of physical, chemical or radioactive substances may result through synergistic relationships.

4. Water quality objectives, criteria, and standards

Efforts to improve or enhance the quality of surface waters must be directed by selected guidelines. Terminology has been an important facet in establishing a context within which a foundation could be laid for decision-making, enactment of legislation, and development of enforcement procedures (Haney, 1953). Objectives, according to McKee and Wolf (1963), represent an aim or goal toward which one might strive, perhaps an ideal condition that would be difficult if not impossible of economic attainment. Criteria are those means by which a surface water might be evaluated in forming a correct judgment concerning it. Each criterion should be capable of quantitative evaluation by acceptable analytical procedures. The term standard is applied to any definite rule, principle, or measure established by authority.

The same connotations were expressed earlier by Haney (1953). Objectives designate or outline the goals of program administration, indicating a desirable end to be reached eventually in a temporal sense, but not of immediate accomplishment. Surface water of pristine quality, or as clean as possible, has been mentioned as an objective by dedicated conservationists (Haugen, 1967). Criteria would be applied to methods of measurement or means of forming a judgment. The term standard implies a rigid legal requirement and carries with it a concept of requiring immediate compliance, or penalties would ensue (Haney, 1953).

The concept of standards established by legislative or administrative authority and accompanied by the attendant problem of enforcement is frequently adopted to represent a real measure of water quality "control." Control has been defined as meaning the public intervention measures required to achieve or maintain levels of water quality necessary for achieving maximum economic return from beneficial use of water (Timmons, 1967).

Two basic types of water quality standards have evolved in the field of water quality control: effluent standards and stream standards. Effluent standards pertain to the quality of the waste or used water to be discharged at a given point. Stream standards or "receiving water standards" pertain to the quality desired in the surface waters into which waste water may be discharged (McKee and Wolf, 1963). These standards of quality should be based on threshold and limiting values for specific properties or potential pollutants in the water, as these potential pollutants affect the beneficial uses to which the water might be put.

As noted by Lyon (1965), "stream standards determine the water uses which are protected and enhanced, while effluent standards usually are used for purposes of control." The masking of the effects of a specific effluent on a receiving stream by other upstream discharges of similar pollutants makes stream standards by themselves particularly difficult to enforce, according to Lyon (1965). He concluded that because water quality management systems in the future most likely will be controlled by forecasts of hydrologic events and desired water quality levels, <u>effluent standards will continue to receive increased emphasis</u>.

Two methods were listed by McKee and Wolf (1963) for designating the level of water quality desired in an effluent standard. The first method was to restrict the concentration and/or the total amount of a substance that could be discharged. The second method was to specify the degree of waste treatment to be provided, or the percentage removal of a specific pollutant that was to be achieved.

Stream standards have also been divided into two separate and distinct categories, dilution requirements and standards of receiving water quality (Streeter, 1949; McKee and Wolf, 1963, p. 29). However, dilution requirements alone should not be considered as a modern-day solution (Hollis and McCallum, 1959). Lyon (1965) stated that establishment of stream standards permitting optimum development of the water resources of a river basin makes it necessary that the people decide what social and public goals are important and which ones are to receive priority.

Several authors have concluded that effluent standards and stream standards are not mutually exclusive, but that one supplements the other and in most cases both are necessary (Haney, 1953; McKee and Wolf, 1963; Lyon, 1965; Burke, 1966). Stream standards, under these concepts, will specify those beneficial uses of water that will be protected and enhanced or improved, effluent standards will serve as a means of control, and maximization of social and economic benefits will take precedence over previously accepted equity concepts in regard to levels of pollutants permitted in effluent discharges (Lyon, 1965).

B. Evolution of Water Pollution Control and Water Quality Standards

1. General considerations

The natural cycle of life and death has revealed a closely interwoven relationship between the plant and animal kingdoms. Waste products of the animal kingdom become a source of nutrients for the growth of plants, which in turn become food for the animals. Although the naturalist or conservationist may speak of "delicate balances" or of "equilibria" as between the two kingdoms in nature, temporally this has not been the case. Geologic and climatic changes of immense magnitude have occurred in past millennia, and these changes slowly but surely continue. The change in the biological environment containing plant and animal life has been equally as great in many parts of the world (Schuchert and Dunbar, 1950). Man, however, has developed through technological innovations the ability to alter his environment to serve a multitude of purposes. Waste products or residues are accumulating in vastly increased quantities as a result of (1) the rapid increase in population, (2) the tendency of people to live in urban concentrations, and (3) the increase in numbers and variety of goods and services produced. Where the capacity of the environment has been insufficient to assimilate these residues, pollution has occurred (National Academy of Sciences, 1966b, p. 3). Although the problem of waste removal involves the interrelationship of land, air, and water, concentration will be placed upon water in this review.

2. Prior to the present century

Remnants of water and waste water facilities predating recorded history have been uncovered in excavations of ancient ruins (Rouse and Ince, 1957). Those in ancient Sumeria date from 3700 B.C. In addition to elaborate bathing facilities, an ingenious water carriage system for waste and storm water existed in the great palace constructed for

King Minos at about 1700 B.C. at Knossos upon the island of Crete (Wright, 1960, p. 4).

The first records of pollution control extend at least 2000 years into antiquity. Purportedly, the religion of the ancient Persians forbade the discharge of wastes into rivers (National Academy of Sciences, 1966b, pp. 66-67). Deleterious effect of wastes upon water quality was noted by the legions of ancient Rome who in conquering new lands judged the quality of local drinking water by the health of the people who had been consuming the water (Wolf, 1966).

The accumulation of residues in areas of population concentration not only caused public health problems, but also concern over (1) the overwhelming mass being accumulated and (2) the increased distances this mass had to be carried for disposal. The industrial revolution intensified the situation, and in England especially, attention was drawn early to the pollution of watercourses (Fair and Geyer, 1954; Wright, 1960; Wolf, 1966). Both the Fleet River and the Walbrook had become offensive by the early fourteenth century (Wright, 1960, p. 51). The ease with which waste disposal could be made to the streams was also evident. A common privy served the occupants of houses built on London Bridge in about 1300. It was said of these bridges that they were "built for wise men to go over and fools to go under" (Wright, 1960, p. 50), thus *indicating an early competitive use of the stream system.*

The first widespread use of the water carriage system of waste removal was employed in England (Wright, 1960; Wolf, 1966). The introduction of the sanitary sewer eliminated the immediate problem of man being buried by his own bodily residues, although today the problem of solid waste disposal is again reaching astronomical proportions (National Academy of Sciences, 1966a, 1966b). The construction of sanitary sewers led to the movement appropriately called the Sanitary Reform. However, the conveyance of raw sewage or other wastes to the nearest watercourse transferred the health problems from the streets to the streams. This arose because the streams and rivers in urban areas were still being used as a direct source of water supply. As a result, typhus and waterborne diseases such as cholera now prevailed over the plague, sweating sickness and black death (Wolf, 1966).

Early engineering periodicals are a source of information regarding health problems and water supply improvements during the 1800's. The importance of obtaining a water supply for the large cities and towns from a country district was evident to the early water supply engineers. It was clearly determined by health statistics that the pestilence of cholera did not select the country for its ravages. Rather, its toll was attributed to cities and towns where imperfect sanitary arrangements were evident, and polluted water had to be consumed (Loudon, 1866). In describing the Manchester waterworks, designed in 1846 and completed in 1850, it was pointed out that the new rural source was designed to replace inadequate and impure sources within the city (Bateman, 1867). Regarding technical alternatives, a novel solution to stream pollution was offered by Beale (1867). He commented that "dirty drains" were always flowing into the millponds, and noted that "all the fish were gone." He then advocated using some of the millpower (a resource allocation concept) to pump the sewage from a collection gallery, to be constructed near the pond, to the distant meadows.

The improvement of public health in London was achieved slowly after creation of a Board of Commissioners in 1848. Their immediate task was reported as the control of London's drainage (Wright, 1960). Through their efforts and those of subsequent Commissions using additional legislation, water supply intakes were moved to upstream locations or to alternate sources and cesspools were replaced by sewers. Completion of the vast new drainage system in 1865 led to a reduction of the death rate by the 1870's (Wright, 1960, p. 156). However, improvements in both the water supply sources and in water filtration methods were corollary developments (Burke, 1966). The magnitude of the pollution control problem in London in the 1860's was tremendous, even at that early date (Wright, 1960). From the north side of the Thames alone, the metropolitan main drainage purportedly had to accommodate 10 million cu ft of sewage daily. There were 83 miles of intercepting sewers, draining 100 sq mi of intensive building areas, and carrying 420 mgd of waste and storm water, with a population of about two and one-half million people.

These various Commissions, although criticized through the years for their ineffectiveness, were credited with leading the way towards modern concepts of waste treatment, pollution control and water quality improvement. Following experiments of "intermittent downward filtration" and of aerobic changes in wastes during treatment, the Commission in the 1870's urged adoption of filtration or irrigation as a standard of treatment (Wolf, 1966). The first surface water standard was thus a treatment or effluent standard. The first water pollution legislation was passed by Parliament in 1876 as the Rivers Pollution

Prevention Act. Ineffectiveness of the act was attributed to grandfather clauses exempting existing polluters and to provisions in the act making enforcement a local problem. This institutional constraint still remains a problem today, according to Clarenbach (1967, p. 72).

During this historic period of development prior to 1900, water quality criteria pertained mostly to public health problems associated with water supplies. Physical criteria of the more obvious characteristics of water were first recommended. Temperature, taste, odor, color and turbidity were observable factors even to laymen, although quantitative evaluation was often lacking (McKee and Wolf, 1963). Chemical criteria were proposed as early as the late 1700's, with additional emphasis in the 1800's. Solids content or residue upon evaporation was an early criterion, followed by ammonia nitrogen and chlorides. Bacteriological criteria were adopted following the development of the microscope and techniques for the culture of microorganisms in the late 1800's.

Urban development in the United States lagged that in England. Serious pollution problems first appeared in the populated industrial areas in the New England states. Commissions were established in Massachusetts and research endeavors commenced at the Lawrence Experiment Station in the 1880's (Wolf, 1966). Extension of sewer facilities, protection of public health, and quality requirements for potable water supplies were of more importance than waste treatment during the last decade of the 1800's (McKee and Wolf, 1963). However, waste treatment methods were being studied, with septic tanks and the trickling filter being developed prior to 1900, and by 1914 the Imhoff tank and activated sludge treatment methods were in use (Babbitt, 1953; Edmonds, 1965, pp. 4-9).

3. Introduction to problems in this century

The problem of pollution involves many problems. Five major problem areas of concern have been listed: (1) the public health problem, (2) the resources problem, (3) the social problem, (4) the economic problem, and (5) the political-institutional-management problem (National Academy of Sciences, 1966b). All of these have received increased attention during the present century, with perhaps public health problems being the greatest early concern and with social and political emphasis receiving the greatest emphasis in the last decade. Historically, all have played a significant role in the evolution of water pollution control, water quality standards, and water quality management in this century. These problem areas will be discussed in the following sections.

4. Public health aspects

Additional insights into the germ theory of disease and development of bacteriological assay techniques were public health contributions during the early decades of the twentieth century (Wolf, 1966). Protection of public health through potable water supply quality has been guided by adoption and enforcement of drinking water criteria and standards. High incidence of and periodic epidemics of typhoid and other water-related diseases assisted in these developments (Berg et al., 1966).

The first drinking water standards were developed in 1914 by the U.S. Public Health Service, utilizing bacteriological, physical, and chemical criteria. Subsequent revisions were made in 1925, 1942, 1946, and 1962. Compulsory for interstate carriers, including the major cities serving the common carriers, the standards have been adopted also by a majority of the 50 states, and guide the remainder (Derby, 1960). These standards were last revised in 1962, at which time radioactive criteria were added and other modifications adopted (U.S. Department of Health, Education, and Welfare, 1962).

Technological developments in the area of public water supply enabled (1) alternative sources of supply to be considered, (2) drinking water to be produced from polluted waters through more sophisticated treatment methods using coagulation, sedimentation and filtration systems, and (3) a bacteriologically safe water to be produced through disinfection techniques. This meant that the public health could be protected to a high degree (Baylis, 1960; Bean, 1960). As a result, stream pollution control slowly lost its public health significance. Because the political-institutional-management area had confined regulatory measures largely to public health, little could be done to control pollution in the absence of specific health problems (Wolf, 1966). However, the public health problem must be kept under constant surveillance, because the elimination or control of one disease has led to recognition and outbreaks of new diseases (Berg et al., 1966).

Of concern today is the public health problem of toxic compounds that endanger desirable species of both plant and animal life. These toxic compounds, including the common pesticidal chemicals, have been categorized into three general groups: inorganic, synthetic organic, and natural organic (McKee and Wolf, 1963). Little research has been performed to indicate the persistence of these chemicals in natural waters (U.S. Senate Select Committee, 1960e).

5. The resources problem

Three major subdivisions of technology within the resources problem area can be identified with regard to the water resource and its related quality. These are (1) water supply, (2) waste water treatment, and (3) stream ecology and concepts of stream or receiving water behavior.

a. Water supply Treatment methods have been developed for obtaining water of a satisfactory quality for the various beneficial uses of water, from either surface or ground water sources (Babbitt et al., 1962). Common methods of treatment in use today include (1) sedimentation, either plain or using a coagulation process, (2) filtration through sand or other porous media, and (3) miscellaneous methods including disinfection, aeration, softening, removal of iron, manganese, and other minerals, control of taste and odors, and correcting corrosive conditions. Although many of the basic concepts of water treatment, including filtration, were known or in use at the turn of the century, technological improvements have kept pace with water demands. Today, a potable water can be produced which is bacterially safe and with certain objectionable substances removed, all in spite of deteriorated stream water quality (Maloney, 1967). Techniques have been developed also for converting saline and brackish water to an acceptable level of quality for various water uses, and desalinization plants can produce substantial amounts of high quality water at a competitive price at some locations (McCutchan and Pollit, 1966). Reclamation of waste water is of increasing importance, especially in industrial processes in which recovery of certain substances is profitable or discharge to surface waters is prohibited (Eckenfelder, 1966, p. 21). This can lead to a "closed" system of water environment in which most if not all of the used water is reclaimed for reuse (U.S. Senate Select Committee, 1960j).

The effect of improved stream water quality achieved in the last two decades has sometimes had an adverse effect upon water treatment. Baxter (1966) reported on the problem of algae and related taste and odor problems which have occurred in water supplies after a turbid or polluted stream was cleaned up.

b. Pollution control and waste treatment Technology in waste water treatment and water pollution control has grown in the present century to provide a broad spectrum of technological approaches and techniques. Eleven physical methods have been identified (National Academy of Sciences, 1966b):

1. Recovery and reuse, including recovery of used water for reuse, and/or recovery of pollutants for beneficial purposes;

2. Waste treatment, including modification or separation of potential pollutants from a waste water, and disposition of the residues in a non-polluting manner;

3. Product modification, the deliberate introduction of new properties into produced materials to reduce their pollutional effects or to enhance their controllability;

4. Process changes, the modification of the process in which a potential pollutant is used or created so that it is not released or its release is reduced;

5. Elimination, the prevention of a potential pollutant from entering the water environment by eliminating its use or generation;

6. Dispersion, the distribution of a waste discharge over a larger area or into a larger volume of water;

7. Dilution, the artificial augmentation of the volume of water used to assimilate wastes;

8. Detention, the temporary hold-up or storage of the production or the release of discharges for later gradual release, or release at a more advantageous time;

9. Diversion, the transportation of a waste to another location for treatment and/or discharge;

10. Environmental treatment, the treatment of the surface water environment to remove pollutants, diminish their effect, or to eliminate or inhibit their generation;

11. Desensitization, the rendering of the potential pollutant harmless through desensitization of pollution receptors.

Developments and improvements in conventional waste treatment processes have been described in several texts and manuals (Fair and Geyer, 1954; Joint Committee, A.S.C.E. and W.P.C.F., 1959; Great Lakes-Upper Mississippi River Board, 1960; Babbitt and Baumann, 1958; Eckenfelder, 1966; Fair et al., 1966, 1968). Four phases of the waste treatment process were outlined by Baumann (1967): (1) preliminary treatment, (2) primary treatment, (3) secondary treatment, and (4) tertiary or advanced treatment.

Emphasis was placed upon the first two phases in early water pollution control efforts to reduce or eliminate "obvious" pollution or nuisance conditions. The source of offensive material discharged to streams was the floating, settleable, and suspended substances found in domestic and industrial wastes (Fair and Geyer, 1954; Lyon, 1965). Heath (1966) indicated that such treatment for protecting stream water quality fell within the concept of "esthetic" stream standards, and in the absence of any other beneficial uses Wendell (1966) referred to this concept as achieving "water that is pretty to look at." Primary treatment of municipal wastes has been effective in removing 50 to 60% of the suspended solids and 25 to 35% of the biochemical oxygen demand (BOD, 5-day, 20 deg Centigrade).

Secondary treatment has consisted of biological treatment using conventional and improved processes of two basic types, activated sludge and trickling filter methods. Secondary treatment used in conjunction with preliminary and primary treatment has increased the overall treatment effectiveness to 90% removal of suspended solids and 75 to 90% removal of BOD (Joint Committee, A.S.C.E. and W.F.P.C., 1959). Baumann (1967) noted that primary treatment units if adequately designed have the potential of removing 98 to 99% of the settleable solids, 60 to 80% of suspended solids, and 30 to 50% of the biochemical oxygen demand from a domestic waste. In addition, secondary treatment units have the capability of removing, in the overall treatment system, 90 to 95% of the suspended solids and BOD present in the raw waste. Intermediate efficiencies, if satisfactory effluent quality is achieved for the purpose of pollution control and stream water quality, can be obtained using chemical treatment and various modifications of these conventional processes (Joint Committee, A.S.C.E. and W.P.C.F., 1959).

Industrial processes have adopted recovery and reuse methods in addition to advanced waste treatment (U.S. Senate Select Committee, 1960j; Eckenfelder, 1966; Weber and Atkins, 1966; Fair et al., 1968). Product modification and process changes should be included as management alternatives in industrial processes. A classical example (Cleary, 1967) of product modification and pollutant elimination is the substitution by the detergent industry in 1965 of biodegradable LAS (linear alkyl sulfonate) for the nonbiodegradable ABS (alkyl benzene sulfonate) in household synthetic detergents.

Dilution has been used frequently as a primary method of water pollution control and as an element in water quality management. Gross estimates of the nation's dilution requirements have been made (U.S. Senate Select Committee, 1960e, 1960i). Low flow augmentation was established by Congress as a nonreimbursable purpose of federal multi-purpose water resources systems in 1961, and its worth in pollution control is now evaluated in monetary terms in federal projects (U.S. Senate, 1962; U.S. Corps of Engineers, 1963, 1964).

Davis (1966) studied the economics of environmental treatment in the Potomac River basin as an alternative to dilution from a storage system of 16 reservoirs proposed by the Corps of Engineers. Stream reaeration devices were proposed as a part of a dissolved oxygen control system. Diversions (effluent distribution) and advanced waste treatment were included in the study. Reaeration as an environmental treatment system was by far the least expensive alternative of the methods studied to accomplish a desired level of dissolved oxygen in the river environment.

Elimination and desensitization of the nutrient load contained in effluents discharged to the stream environment have received increased attention in the last decade (U.S. Senate Select Committee, 1960e). Newer methods have been proposed including ammonia stripping and phosphate removal (Middleton, 1966; Schaeffer, 1966).

New production processes and rapid development of new industries, such as the petro-chemical industry, have resulted in vast new water pollution problems (U.S. Senate Select Committee, 1960e). These industrial problems will require an additional advanced or tertiary stage of waste treatment to increase BOD removal and to provide removal of specific pollutants. Technical research of advanced treatments and of systems operation has been recommended (Gloyna, 1966; Baumann, 1967). Numerous accomplishments in the area of advanced waste water treatment have been summarized recently for physical, chemical and biological methods (Weber and Atkins, 1966; Schaeffer, 1966; McKinney, 1966). Gloyna (1966) also reported that the end point for physical returns which can be obtained through technical efficiency was rapidly approaching for secondary (biological) treatment. This was attributed to the lack of operational supervision to achieve the design capabilities or the treatment expectations. Seidel (1967) also expressed concern about the operational phase of water pollution control, including operational budget and personnel problems.

c. Stream ecology and behavior The study of stream ecology relating to water pollution control developed historically within the context of "sanitary science" and was afforded the title "stream sanitation" by Phelps (1944). He emphasized the broad field of science which was involved, including elements of biology, microbiology, chemistry, biochemistry, bacteriology, physics, mathematics and law. The pollution and self-purification of streams received major emphasis during the early development of stream sanitation for raw sewage was being conveyed by sewers to the nearest watercourse (Streeter and Phelps, 1925). The historic development of stream sanitation was traced by Streeter and Phelps (1925) to several basic advances in technology. First was the discovery of principles governing the growth and death rates of bacteria, leading subsequently to knowledge of the complex biochemical reactions which are involved in stream purification. Second was the evolution of the biochemistry of sewage and sewage-polluted waters. Finally, modern physical chemistry came as an aid in interpreting and applying the results of biochemical methods. The fundamental mechanisms governing self-purification of streams were identified by the mid-1920's (Streeter and Phelps, 1925; Babbitt and Baumann, 1958) as consisting of (1) dilution, (2) sedimentation, (3) reduction, (4) oxidation, (5) reaeration, and (6) the effect of sunlight and solar energy upon chemical, physical and biological activity.

Through theoretical and experimental research, many advances in each of the six areas have been accomplished in the last four decades. Beginning with the "oxygen sag" equation of Streeter and Phelps (1925), mathematical formulation of these mechanisms of assimilation and self-purification has permitted stream behavior to be studied quantitatively. Temporal and spatial variations of certain water quality parameters could now be determined, at least for the more simple waste products and substances commonly found in municipal wastes (Streeter and Phelps, 1925, Phelps, 1944; Thomas, 1948; Fair and Geyer, 1954; Streeter, 1958; U.S. Public Health Service, 1958; Courchaine, 1963; Gunnerson and Bailey, 1963; Camp, 1965; O'Connell and Thomas, 1965; Berg et al., 1966; Gannon, 1966; Purdy, 1966).

However, Baumann (1967) noted that many unknowns still exist today concerning a stream's reaction to wastes and the eventual effect upon downstream water uses, with the most difficult water treatment problems pertaining to taste and odor problems in surface waters. Maloney (1967) has also listed among water problems the lack of knowledge in specific streams due to (1) synergistic and antagonistic effects, (2) rates of decomposition and flow characteristics of pollutants under variable stream and effluent conditions, (3) new organic chemicals, and (4) the limitation of data available on streams due to the infrequency of sampling. This latter problem has been noted by others (Kneese, 1962; National Academy of Sciences, 1966b), and it was concluded that streams, rivers, lakes, groundwater and estuaries have not yet been studied sufficiently or sampled intensively enough to permit making reliable predictions of the fate of pollutants in surface waters.

6. The social problem

The lack of interest in water pollution control following improvements in water supply treatment methods during the early 1900's was noted previously. A scattering of lawsuits by private individuals or groups seeking private redress was the first reaction to pollution problems (Wendell, 1966). Public enforcement policies, where they did exist, had many deficiencies. Conservationists wanted water of pristine quality, polluting industries had enormous economic importance and political power, and municipalities pleaded fiscal impossibility (Clarenbach, 1967; Hines, 1966a).

Pollution control efforts in the United States gained support in the 1930-40 depression period due to public works programs. Control efforts were sidestepped in the early 1940's due to the war effort during World War II. Movement of pollution control interest into domestic government programs began in earnest in the late 1940's (Water Resources Policy Commission, 1950). Rapid expansion of industrial activities and increasing urbanization trends in the 1950's resulted in a tremendous emphasis upon pollution problems and control efforts through public acclaim, news media, and other means of communication. Emphasized by droughts in the 1950's and early 1960's, the problems of water shortages, water quality and pollution became popular topics. Gross pollution in many areas of the nation were reported (Lear et al., 1965) and the crises in water debated. Problems in major metropolitan areas received the greatest attention (Pugh and Ball, 1966).

The effect of aroused social action has resulted in additional water pollution control and water quality legislation, both at the national level and in several states (Hines, 1967b). The magnitude of this effect was reported by Hines in discussing the swift passage of the comprehensive Iowa Water Pollution Control Act of 1965 by the Iowa General Assembly as a noncontroversial item and thereafter signed into law by the Governor almost immediately. Hines concluded that "it is doubtful that comprehensive legislation .... ever generated less serious discussion and debate in a state legislature."

7. The economic problem and financial assistance

a. The role of economics   Kneese (1962, 1964, 1967) has consistently emphasized the fact that the basic economic institution on which a society usually depends to balance the costs and returns for the use of resources does not operate satisfactorily for waste disposal. In economic terms, this institution is referred to as the interaction of market forces in a private enterprise system.

Economists commonly have been in agreement that a well-functioning market system is an efficient mechanism for allocating resources in correspondence with consumer wants (Leftwich, 1960; Kneese, 1962). If highly competitive markets exist, and consumers and producers are rationally striving to achieve the greatest possible benefit for themselves, the available resources will be allocated in a manner which maximizes economic welfare. Each productive resource will be employed up to the point at which the cost of an additional unit is just equal to its contribution to the value of production. Within the economy, the market price of the resource is equal to its opportunity cost.

Also, the consumers striving to achieve maximum satisfaction from a given amount of income will tend to regulate or allocate their expenditures in such a manner that the last dollar spent for any particular item will yield an amount of satisfaction that is equal to that received from the expenditure of the last dollar spent on any other item. At the margin an additional dollar's worth of any good equals the dollar's worth of any other good. Under this condition, the market price of a specific good reflects its worth, or want-satisfying power, in the economy. If, as one last condition, the distribution of purchasing power conforms to the ethical standards of the community, and consumer sovereignty over resource allocation is accepted, the prices of goods and the factors of production accurately represent their contribution to social welfare. Private benefit maximization is to indicate and induce the shifts of resources which are encountered under various circumstances, and when the shift is made, the total value of production is enhanced and total satisfaction derived by society from its consumption of resources is thereby increased (Kneese, 1962, p. 19).

Thursby (1966) noted that economic analysis is considered to be the most effective means for determining the best combination of physical factors which will produce the greatest net benefits from limited expenditures. The budget constraint should therefore be recognized. The optimum use of resources implies that all attempts should be made to achieve a balance in which the marginal benefits to be derived from programs for improving water quality equal the marginal costs of producing these same benefits.

As related to both water quantity and quality, three types of economic relationships have been identified (Timmons, 1967). These relationships are (1) neutral, (2) complementary, and (3) competitive. Neutral relationships exist when one use has no effect on the quality of other uses. When uses are neutral to each other, as might be the use of the stream environment for navigation and waste disposal, no decision on water quality is needed. Complementary relationships arise if one water use upgrades the water quality for a second use, without the converse effect occurring. The first use, therefore, complements the quality for the second use. Although the incidence of added benefits to the second use, and the equity thereof, is in question, there are no real water quality conflicts. A municipality with a groundwater source (cool temperatures) might conceivably discharge a cooler than normal effluent to a stream, with the water being used subsequently by a power plant for cooling water — or they might conceivably make joint use of a cooling pond, the municipality as an effluent sink, the power plant as an influent source.

Competitive relationships between quality uses of water arise when one use conflicts with another use or uses. Conflicts between waste discharge and recreation are among those most commonly experienced (Water Resources Policy Commission, 1950). The competitive relationship has been described as the core of water quality problems (Kneese, 1964; Timmons, 1967). As noted by Kneese, water uses that do not cause any productive opportunities to be foregone are socially costless.

The initial problem in a water quality improvement program formulation is determining the quality and amount of water that can be used economically at a particular time and place for each competing use. Through such an analysis of all competing uses, the aggregate demand for water may be estimated and allocation criteria formed (Timmons, 1967).

Although simply expressed and highly idealized, these basic economic concepts have provided a social justification for introducing market processes and political justification for public intervention in instances where some type of obstruction prevents marginal theory from operating. An essential condition is recognized by Kneese (1964) for obtaining ideal market results. The technical conditions of production and consumption must be such that the full costs and benefits of any given act fall upon the production or consumption unit performing it. If some costs can be shifted to other economic units, the private costs incurred fail to correspond to the social cost of production, as expressed by the value of production foregone. Resource allocation is thereby noted to be distorted, although markets may continue to function in an otherwise satisfactory fashion. These indirect effects are defined as "spillover effects" or "external diseconomies." In water pollution, these effects have become significant, requiring correction through public policy (Kneese, 1964).

"Technological external diseconomies" are noted to be the most significant factors in water pollution, according to Kneese. These uneconomical results (diseconomies) have an incidence upon outside or other economic decision units than the one performing the waste discharge (external unit), and are independent thereof. The cost transfer is achieved through a technical or physical linkage between production processes (technology). Internalizing these external opportunity costs is an alternative to be considered in water pollution control, but appears to be of limited use according to Kneese (1964).

Resource misallocation occurs most frequently when discharge of wastes into a stream causes additional costs or preclusion of uses farther downstream. Thus, the production costs of the waste discharge are understated relative to the social or opportunity costs. According to Kneese, from the social point of view, the value of the water resource is measured by the alternative uses that can be made of it. He concluded:

> (a) Failure of municipal and industrial waste dischargers to consider that subsequent water uses may be made more expensive or foreclosed entirely by the discharge is

perhaps the basic element of the water pollution problem, and

(b) A society that allows waste dischargers to neglect the offsite costs of waste disposal will not only devote too few resources to the treatment of wastes, but will also produce too much waste in view of the damage it causes.

These technological external diseconomies have been further divided into "separable" and "inseparable" or "nonseparable" categories (Kneese, 1962, 1964). Nonseparability also leads to reciprocal and nonreciprocal forms. In separable externalities, only fixed costs of affected downstream water uses would be influenced, and optimum output is no different than it would be in the absence of the externality (Leftwich, 1960). In nonseparable externalities, the marginal cost in a productive process is affected by the level of output in another process. Interactions are created between the decision making units, and the downstream use must know the output level of the other plant before determining its production level. An additional case of non-separability is noted when two industrial waste dischargers with the same type of effluent are situated, for instance, opposite each other along a stream which has downstream water users affected by the level of pollution.

Externalities, within the technical area, but involving reciprocal and nonreciprocal aspects have also been identified (Kafoglis, 1967; Kneese, 1964, pp. 85-98). The externality is nonreciprocal if, for example, an independent change in the output of one firm affects the costs of a second firm, but output changes initiated by the second firm have no effects upon the costs of the first. If the relationships are symmetrical, each one's actions affecting the other, the externality is reciprocal in nature. The distinction between "Pareto relevant" and "Pareto irrelevant" externalities was described also. Those which are of real concern and affect policy or decision making are relevant; those which do not are of little real concern.

Two other types of externalities have been identified with water resource problems, in addition to technological externalities (Bator, 1958). These are "ownership" and "public goods" externalities. In the first, the basic cause of market failure is nonappropriation or the inability of the owner of a factor of production to charge for the value of the services because of legal or other reasons. An example might be a hydroelectric plant having a large storage reservoir and fairly continuous water releases such that the water is of increased value for dilution during natural low flow periods at points of downstream waste discharge. Public goods externalities occur when an individual's consumption of a good leads to no reduction or subtractions from any other individual's consumption of that good. Street lighting is an example frequently used to illustrate this effect. Therefore, there is no need to ration public goods between individuals, and no set of market prices for public goods is useful for decision making purposes. There is no set of market prices which will efficiently ration any fixed quantity of public goods. Both of these types of externalities are considered to be important in water recreation activities (Davidson et al., 1965).

"Pecuniary" diseconomies also exist, with a considerably different significance (Kneese, 1964; McKean, 1958). A pecuniary diseconomy arises essentially when a third economic unit is priced out of the market, and as noted by McKean, is the result of a shift in prices. This could occur, for example, through negotiation between a water purveyor and a customer, or by other units bidding more for available but scarce water which is needed by all in various production processes. An example would be an industry with a highly consumptive use which purchases water or water rights to streamflow and thereby eliminates a recreation use presently paying for the water. The two general types of spillovers or diseconomies, technological and pecuniary, are in principle distinguishable and mutually exclusive.

b. <u>Economic goals</u> These special circumstances, which encompass the waste disposal and water pollution problem causing the market system to operate imperfectly or not at all, have been recognized as grounds for public intervention and for action in the political arena in the general process of public policy formation (Kneese, 1962, 1964; Smith, 1967). These circumstances can be expressed in some form of economic relationship. Timmons (1967) noted that the economic dimension can play a prominent role in making decisions about (1) desired levels of water quality and (2) the technological means for achieving particular water quality changes or improvements.

Davis (1966) expressed the same concepts, questioning in economic terms

> (1) what is the optimal scale of expenditures for water quality improvement (how much are we willing to pay for it), and (2) what is the least cost solution among alternatives for achieving a given scale of output, or what is the most efficient technical means of accomplishing a given level of water quality improvement.

Renshaw (1958) expressed concern that pollution control agencies, acting as public intervenors, may not have sufficient information to determine (1) the highest use to which a limited amount of water can be put, (2) the optimum degree of pollution that might be permissible, or (3) the optimum degree of waste treatment which stream classification, stream standards and effluent standards presume the authority can determine.

c. Programs for economic assistance In the private enterprise system which prevails in the United States, it has been shown that in the case of waste discharge a municipality or industry at an upstream location is not induced by the market to take into account automatically either the additional water treatment costs imposed on downstream users, or the value of alternative water use opportunities foregone because of pollution resulting from the upstream effluent discharge. Equivalent economic problems have been encountered in the socialistic nations, in Russia, for example (McKee and Wolf, 1963, p. 31). Economic programs of financial assistance, which consider both the benefits and costs of water quality improvement (Water Resources Policy Commission, 1950; Kneese, 1967), have been developed to supplement the inability of the market, or of management decision making.

Civic responsibility has been used as a simple means of encouraging municipalities and industries to expend funds to reduce waste contributions to streams (Kneese, 1967). Private remedies sometimes are sought through the courts, wherein injured parties have taken action to seek recompense for the damage suffered, or to enjoin the pollution activity causing harm thus preventing additional economic loss, or both remedies have been sought (Hines, 1966a). However, economic incentives accompanied by legal restraints are noted to be the two most effective methods for supporting an adequate program of water quality improvement (Nicoll, 1966). Economic incentives provide a source of financing for meeting the large capital expenditures which are required to construct major interceptor sewers and waste treatment facilities. These incentives have been introduced at all three levels of government, local, state and federal (Clarenbach, 1967).

At the local level, economic assistance for water pollution control has been provided in a variety of ways, including (1) private enterprise, (2) general taxation, (3) special assessment, (4) general obligation bonds, and (5) revenue bonds (Babbitt and Baumann, 1958; Fair et al., 1966). A system of sewer charges has been introduced and collected by many local communities, normally based upon the quantity of potable water used but sometimes a flat charge per consumer is used. This system of charges serves as an expression of the economic benefit to a water user of water pollution control, and the charges serve as a basis for repayment of revenue bonds and for operation and maintenance costs (Fair et al., 1966, pp. 18-25; Hines, 1967b; Iowa Code, 1966a:391.13). In an economic sense, the system of sewer charges reveals to the consumer that the total cost of a water supply includes both the cost of obtaining the potable water and of disposing the used water.

Of the several states which have provided economic assistance in the field of pollution control and water quality management, New York has accomplished the most (Clarenbach, 1967). Voters in New York State approved a billion dollar bond issue in 1965, indicating that large state grants for construction of municipal waste treatment facilities were favored. However, more recently the voters of Illinois (1968) and Texas (1969) defeated such a proposal. Special tax incentives have been provided by some states to industries with waste treatment works in recognition of the unequal status of industries disposing of wastes through municipal systems and those that must provide their own treatment (Hines, 1966a). Additional methods to aid construction include direct grants and/or loans, planning assistance, and in one state (New Hampshire), the municipal bonds issued for waste treatment works are guaranteed by the state, according to Hines (1966a).

It was recently reported (National Association of Manufacturers, 1965) that over 100 million dollars were spent by industry in 1959 for operation of waste treatment facilities, and that plant replacement cost, at 1959 prices, was estimated at more than one billion dollars. However, of anticipated spending of 170 million dollars for both water supply and waste disposal projects then in the planning phases, only 10% was for waste water disposal, thus relegating the latter to a small portion of the overall water use role.

The federal role in economic assistance began as a result of technological advances in sewer construction but inadequate provision for waste treatment facilities. Sewer construction was initiated in the 1880's in the United States, and local efforts in providing sewers far outran provision for waste treatment plants (Water Resources Policy Commission, 1950). In 1950, there were 9,000 sewer systems in operation compared to 16,000 waterworks. Only 6,000 sewer systems discharged through a treatment plant. It was concluded in the 1950 report that

<u>federal economic incentives as well as regulatory measures were necessary</u> because of the following problems:

1. Construction of waste treatment facilities lacks appeal for local taxpayers, who may face other pressing needs and statutory borrowing limits.

2. Many streams and lakes have an interstate character, and a lack of uniformity of state regulations may exist.

3. In the field of industrial waste treatment, construction and operation of waste treatment facilities reduces corporate profits and requires large capital expenditures.

4. Private industry is competitive, and construction of waste treatment facilities may reduce a company's competitive margin.

5. Cities and states are reluctant to adopt stringent anti-pollution laws requiring substantial expenditures for fear of driving out industries.

Federal economic assistance first became noteworthy during the depression of the 1930's. Through two programs, the Works Progress Administration (WPA) and the Public Works Administration (PWA), federal aid was funneled into water pollution control. Through these public works and work relief programs, much progress was made between 1933 and 1940, as compared to the previous 30 years of the century. Many waste treatment plants were constructed during this period, primarily for municipalities (Water Resources Policy Commission, 1950).

Hines (1966a, 1966b, 1967a, 1967b) in an extensive study outlined the growth of the federal government's role in water pollution control, including both the economic assistance and institutional phases. This growth commenced with the passage of the Water Pollution Control Act of 1948. It authorized the appropriation of funds for support in three major areas: grants for research in water pollution, grants for preliminary engineering studies and surveys for project design purposes, and loans for construction of necessary waste treatment works. One million dollars was authorized annually for five fiscal years for each of the first two items, and 22.5 million dollars annually for the same period to provide loans to local entities for construction of waste treatment facilities. However, no funds were appropriated for fiscal year 1949, and by 1952 only 9.4 million dollars of the 83.4 million dollars originally authorized for the three areas of support were actually appropriated.

Amendments in 1956 replaced the construction loan program with a construction grant program. Expansion of the economic assistance program was made successively in 1961, 1965, and 1966 (Hines, 1967a). The Federal Water Pollution Control Administration has reported on the success of the construction grant program since the 1956 amendments were adopted (Barnhill and Levenson, 1965). Annual contract awards, in which federal participation was involved, increased from 266 million dollars to 432 million dollars in the period 1956-1961. Construction expanded again following the 1961 amendments, and annual contract awards reached 539 million dollars in 1961, 654 million dollars in 1962, and jumped to 815 million dollars in 1963, reflecting an additional 108 million dollars granted under the Accelerated Public Works Program. The annual contract awards dropped to 600 million dollars in 1964. The amount of federal grants since 1956 reached a total of 678 million dollars by September 30, 1965, with a total project cost of 3.2 billion dollars. Despite the progressive increase in annual contract awards, however, it was reported that construction was still below the level needed to bring the municipal waste pollution problem under control during the present decade. Hines (1967a) reported that in fiscal 1966, following the 1965 amendments, the F.W.P.C.A. dispensed over 157 million dollars through five different types of funding programs, including construction, research, training, demonstrations, and operating programs. Many additional sources of economic assistance were also noted, which were available under separate federal programs.

8. <u>The political-institutional-management problem</u>

Individualism in a nation becoming increasingly urbanized and industrialized gradually becomes more and more subjected to public regulation through common laws, statutes, administrative rules, etc. This is attributed to the many conflicts of interest which arise between individual desire and the general interests of the society in which the individual lives.

Heath (1966) divided into two dimensions the problem of practical limitations being encountered in water quality regulation. The first involved the individual polluter, the second dealt with polluters in the mass. In dealing with matters of individual concern, he asked: "...how far can one go, in the name of an overall scheme of regulation, in coercing an individual regulated unit even to the extent of confiscation?" The answer then given was expressed in terms of "substantive due process" or, what degree of regulation was permissible in view of the constitutional prohibitions against deprivation of property without due process of law, etc. Under the concept of public interest, Heath concluded, some coercive or confiscatory effects are constitutionally acceptable, as supported by court decisions in zoning, etc.

a. Actions by private individuals Water pollution control through restraining efforts of private individuals preceded public controls. The earliest legal restraints were accomplished through the common law rights and duties as developed under the riparian system of water rights (Adams, 1956; Davis, 1956; Peterson, 1966; Clarenbach, 1967; Hines, 1967b). This stated in essence that those owning land contiguous to a watercourse could expect to have the water flow by their property "undiminished in quantity and unimpaired in quality." Strict interpretation of this theory implied no consumptive use of water, and no change in water quality whatsoever. The "reasonable use" theory modified the earlier riparian theory, and permitted riparian owners to make use of the water as long as each owner's use did not interfere unreasonably with the use of another riparian owner. In instances of alleged pollution, actual damage had to be proven and each case required individual court action. If damages were proven through establishment of unreasonable use, a riparian owner could seek payment of damages, an action to enjoin the pollution action, or both remedies could be requested, as was mentioned previously (Clarenbach, 1967, p. 74; Hines, 1966a, 1967b).

Hines (1966a, 1967b) summarized the status of individual action, stating that the private remedies which were available never proved to be effective restraints for the control of water pollution. There were too many difficulties in obtaining the necessary evidence, identifying the polluters, and proving the case in a court of law. Clarenbach (1967) concluded that piece-meal actions were costly, and generally inadequate for coping with water pollution broadly and effectively. Public controls, therefore, were introduced.

b. Public control measures The first public control measures were attributed to the efforts of county attorneys at the county government level (Hines, 1967b, p. 53). The county attorneys, on behalf of the citizens, could bring an action to abate a public nuisance, a regulation measure gained through the state police power in protection of the public health, safety and welfare. However, the state governments prior to 1948 exercised the chief control over water pollution problems, although prior to the turn of the century certain functions were delegated to smaller political entities (Clarenbach, 1967; Hines, 1967b).

The courts have consistently upheld water pollution regulation as a valid exercise of the state's police power (Resh, 1956; Hines, 1966a). In view of the inherent danger of pollution to public health, safety and welfare, it represented a classic example of the application of the police power. Even in borderline instances of pollution, wherein esthetics may be the sole concern, the courts in all probability would support the regulation. In regard to the vested rights of individuals, Hines (1966a) stated that if the end to be achieved by regulation has adequate social importance, sufficient to outweigh the interests of the individuals being injured, the courts might uphold the regulation of vested rights. Further, the great community concern about water pollution weighs heavily in favor of public regulation, and the courts uniformly have supported the delegation of authority by a legislative body to a control agency. Thus, the various state and federal water pollution control agencies assigned with the responsibility of achieving water quality control have developed under these concepts.

c. Achievements in Iowa The initial public water pollution control statute in Iowa (Houser, 1967; Schliekelman, 1967) was an 1861 law. It contained a section stating that corrupting or rendering unwholesome or impure the water of any river, stream, or pond was deemed a public nuisance for which court action and penalties were prescribed. An 1873 act provided for imprisonment and/or fines for "throwing or causing to be thrown any dead animal, night soil, or garbage into any river, well, spring, cistern, reservoir, stream or pond, and onto any land adjoining which is subjected to overflow."

The first comprehensive state legislation in Iowa for water pollution control was enacted in 1923 (Schliekelman, 1967). Known as the Iowa Stream and Lake Pollution Law, it designated the State Department of Health as the administrative agency. It remained in force with few changes for 41 years. In regard to pollution abatement, the law provided for investigations of pollution on the initiative of the Department, or upon petition, for the calling of hearings, and for the issuance of orders to cease and desist (Iowa Code, 1962). Additional regulations provided for issuance of permits for sewers and waste treatment facilities, and for other public health measures.

The accomplishments under this act, in regard to municipal sewerage systems in Iowa, were reported by Houser (1967) for the period up to June 30, 1965. At that time, only 465 incorporated municipalities of a total of 944 had sanitary sewer systems, but the percentage of the municipal population served by sewers was about 93%. All major urban areas had sanitary sewer systems. A total of 424 municipalities were treating their wastes, or 97.5% of the total population which had sewerage systems. However, the adequacy of treatment was not listed; some plants reportedly were not providing satisfactory treatment and others provided only primary treatment. During the period 1956-1965, 29 new plants and 106 enlargements or replacements of existing plants were constructed or were under construction under the federal aid program. Of the total construction cost of about 62.5 million dollars, the federal contribution through grant allocation was 10.6 million dollars. A total of 96 local projects were installed without outside aid during this same period. The then current recommended needs were listed: 41 new plants for treatment of raw sewage, 66 enlargements or replacement projects, and six plants for new sewer systems. All of these improvements were needed to provide a higher quality of water in the receiving streams.

Morris (1967) attributed the increased awareness of the pollution problem for the ease with which new legislation was enacted in 1965 in the form of the Iowa Water Pollution Control Act (Iowa General Assembly, 1965). The two principal additions (Schliekelman, 1967) to the previous legislation were (1) the creation of a Water Pollution Control Commission of nine members (increased to 11 in 1969) representing all affected interests in the state such as public health, conservation, fish and wildlife, water resources, education, agriculture, industry, municipalities and the public at large, and (2) authority for the adoption of stream water quality standards and effluent standards. Codified as Chapter 455B (Iowa Code, 1966b), the act provides that in adopting, modifying, or repealing quality standards for any waters of the state, the commission shall give consideration to:

1. The protection of the public health;

2. The size, depth, surface area covered, volume, direction and rate of flow, stream gradient, and temperature of the water;

3. The character and uses of the land area bordering said waters;

4. The uses which have been made, are being made, or may be made of said waters for public, private, or domestic water supplies; irrigation; livestock watering; propagation of wildlife, fish, and other aquatic life, bathing, swimming, boating, or other recreational activity; transportation; and disposal of sewage and wastes;

5. The extent of contamination resulting from natural causes including the mineral and chemical characteristics;

6. The extent to which floatable and settleable solids may be permitted;

7. The extent to which suspended solids, colloids, or a combination of solids with other suspended substances may be permitted;

8. The extent to which bacteria and other biological organisms may be permitted;

9. The amount of dissolved oxygen that is to be present and the extent of the oxygen demanding substances which may be permitted;

10. The extent to which toxic substances, chemicals or deleterious conditions may be permitted;

11. The need for standards for effluents from disposal systems.

The success of a state's control program in protecting the quality of its streams will depend primarily on two factors, according to Hines (1967b): (1) the comprehensiveness of the pollution and water quality legislation and (2) the character and efficiency of the regulatory agency administering the control program. Pertinent elements of the Iowa act which meet these requirements are:

1. Declaration of policy, articulating the nature of legislative concern underlying the statute,

2. Definitions of terms of particular significance,

3. Representation of membership of the commission and its integrity,

4. Powers and duties of the commission or administrative agency, including:

   a. to generally administer and enforce the water pollution laws,

   b. to develop comprehensive plans and programs to deal with pollution,

   c. to cause the investigations of alleged pollution situations,

   d. to adopt and change water quality standards for any waters of the state as it deems necessary,

   e. to review and approve or disapprove plans for disposal systems and to control the issuance, modification and revocation of permits for the installation and operation of disposal systems,

   f. to make rules and regulations necessary for the conduct of the commission and the carrying out of its responsibilities,

   g. to cooperate with other state or interstate pollution control agencies in establishing quality standards for interstate waters,

   h. to hold hearings necessary to discharge its duties.

Two problem areas which may arise in Iowa were specifically noted by Hines (1967b): (1) a need for encouraging the development of local responsibility for pollution control and (2) a need for enabling provisions. The Iowa statute does not provide for creation of special local agencies for pollution control, a necessary item for effective police action in the long run. The second problem area relates to the necessity of including provisions to assist potential polluters in the construction of adequate treatment facilities. Such a provision was used by New York State, for instance, in passing a state bond issue providing for state grants (Clarenbach, 1967). In view of the federal financing programs which provide incentives for state assistance, such enabling provisions appear to be needed in Iowa.

d. <u>The federal role</u> The federal government was a latecomer to the water pollution control and water quality regulation picture, in terms of active and massive legal and financial support. Although some 100 bills dealing with the overall problems of pollution had been introduced into Congress in the first 50 years of this century, it was not until 1948 that formal water pollution control legislation was enacted (Water Resources Policy Commission, 1950). Prior to this time, legislation had been limited to pollution problems on navigable waterways and interstate streams. Hines (1967a), however, pointed out that federal action in these matters antedates most state activities in the field of pollution control. In 1912 the Public Health Service received authorization to make investigations of the health effects of pollution in navigable waters, and, in cooperation with local and state officials, accomplished a great deal with the acceptance of drinking water standards. Although the temperament of Congress became more favorable to comprehensive water pollution control legislation, including enforcement, in the late 1930's, no legislation was passed prior to World War II (Hines, 1967b). However, several states were even then participating in interstate compacts within a framework of Interstate Sanitation Commissions, including New York, New Jersey, and Connecticut (Water Resources Policy Commission, 1950).

The Water Pollution Control Act of 1948 declared it to be congressional policy to recognize the primary responsibilities and rights of the states in controlling water pollution. The economic assistance provisions of this act, as discussed previously, provided for construction loans and not outright grants. The federal government under this statute had no original enforcement powers other than that of holding public hearings on individual pollution violations in interstate waters (Water Resources Policy Commission, 1950). Even if pollution constituting a public nuisance was deemed to exist, the abatement provisions were extremely limited (Hines, 1967b). Therefore, the act served primarily as the first official recognition of the need for some type or degree of federal involvement in the regulation of water quality.

Amendments in 1956 and 1961 increased federal involvement, but primary responsibility remained with the state water pollution control agencies (Hines, 1966a, 1967a). In the 1961-1965 period, additional attention was given by Congress to the water pollution problem with the need for two changes becoming evident as the period ended (Hines, 1967a). These were the demands for a separate federal water pollution control administrative agency, and the need for the establishment of federal water quality standards, considering both receiving water standards and effluent standards for all interstate or navigable waters. The legislation which ensued is known as the Water Quality Act of 1965 (U.S. Statutes 79:903, 1965). Hines (1967a) listed the following changes in water quality regulation:

1. It provided for the creation of water quality standards by the states for interstate waters, including a timetable therefor; the standards to be adopted and utilized by the federal agency in regulating interstate pollution.

2. In absence of effective state action, the Secretary (of Health, Education, and Welfare) was authorized to formulate the standards;

3. The act provided certain procedural safeguards to assure reasonable action in formulating, approving, and revising standards.

4. It created the Federal Water Pollution Control Administration as a separate agency within the Department of Health, Education, and Welfare.

Immediately upon passage of the act, it was signed into law by the President who then submitted to Congress a Reorganization Plan transferring all activities of the new Federal Water Pollution Control Administration (FWPCA) into the Department of the Interior. The plan went into effect in May, 1966 (Hines, 1967a).

In May, 1966, the FWPCA issued guidelines for establishment of water quality standards for interstate waters under the provisions of the 1965 act (U.S. Department of Interior, 1966). Twelve additional policy guidelines were transmitted to the states to guide them in establishing water quality standards. The guidelines provided that:

1. Water quality standards would be designed to "enhance the quality of water" and standards that do not at least maintain existing water quality would not be acceptable.

2. No stream can be used for the sole purpose of transporting wastes.

3. Identifying water quality criteria are to be applied, with quantitative, numerical values if available and applicable.

4. Governing criteria should be defined in terms of the time period of measurement and limiting values; and the specified recurrence and duration of the design streamflow should be listed.

5. Standards should provide for potential and future water uses as well as for existing uses, and polluted waters should be improved in quality.

6. A plan for implementing and enforcing the adopted water quality criteria is to be included, accompanied by time schedules and actions to achieve compliance, controls and surveillance methods, and enforcement authority.

7. The water quality plan should consider all relevant sources of pollution from all beneficial uses.

8. No wastes are to be discharged without treatment or control if such wastes are amenable to treatment, and shall receive the best practicable treatment normally.

9. States are to hold public hearings required in the provisions of the act, with summaries of hearings to be forwarded.

10. In interstate waters, standards are to be compatible with those of adjacent states.

11. Standards of water quality should conform to any comprehensive water pollution control programs, both existing and planned.

12. Standards are to provide for future growth and needs.

The Water Quality Act of 1965 included a policy clause "to enhance the quality and value of our water resources and to establish a national policy for the prevention, control, and abatement of water pollution." The comprehensiveness of its geographical coverage was given in the definition of the term "interstate waters" as meaning all rivers, lakes, and other waters that flow across or form a part of state boundaries, including coastal waters. Therefore, within this definition, waters that flow across or form a part of state boundaries were included, this also meaning the entire stretch of such a river (U.S. Department of Interior, 1966). In addition, pollution of an interstate stream by an intrastate tributary was made subject to abatement proceedings.

e. Regional interstate compacts Prior to the extension of federal interest and regulation through legislation, a river basin or regional approach to water pollution control and water quality improvement was sometimes accomplished through interstate agreements and compacts, or more informal interstate groups. Hines (1966b) discussed these in detail, noting that the informal groups lacked regulatory power. Historical development of formal interstate water pollution control agencies include the (1) Tri-State Compact involving New York, New Jersey, and Connecticut, (2) Interstate Commission on the Potomac River Basin, (3) the New England Interstate Water Pollution Control Compact, and (4) the Ohio River Valley Water Sanitation Compact, or ORSANCO. The accomplishments of the latter, ORSANCO, in cleaning up the polluted Ohio River have been reported by Cleary (1967). The Delaware River Basin Commission, established in 1961, provided for comprehensive planning and management of a basin's water resources, including water pollution control. The combination of state and federal participation in the planning and implementation phases, and of the powers of each level of government, were considered unique (Terenzio, 1962; Clarenbach, 1967).

C. Summary

Governmental decisions to maintain or improve water quality may be implemented today by one or more of three basic kinds of measures, according to Clarenbach (1967):

1. Direct regulation, and the formal, explicit setting of water quality standards that may or may not be part of a system of direct regulation.

2. Economic assistance and incentives in the form of grants or payments from the federal and/or state governments to local pollution control agencies.

3. Charges which may be levied for the treatment of wastes and for the disposal of effluents or other pollutants directly or indirectly into public waters.

In regard to intergovernmental relations in water quality control, Wendell (1966) noted that the concept of water quality standards included in the 1965 federal act was a compromise between those who wanted immediate determination of standards by the federal government, and those who wanted the entire matter left to the states. He noted that in such a "shotgun wedding" many problems arise which will have to be coordinated between state and federal governments. Wendell concluded that the guidelines issued by the Department of Interior (1966) had some conflicting statements in regard to this intergovernmental relationship, and that the concept of the 1965 act that "waters should be kept as clean as possible" was not a workable scheme at all without the application of value judgments.

Clarenbach stated that whatever "mix" of institutional forms and financial assistance that are adopted to achieve water quality control, there exists a great need for regional planning of water quality management. Wendell (1966) also mentioned the possible beneficial use of joint federal-state and federal-interstate planning bodies for the development, management and conservation of water resources including water quality which are now permitted under the Water Resources Planning Act of 1965. Such a system would provide for a regional joint commission with the potential of yielding the most meaningful results in regard to water pollution control and water quality improvement. Kneese (1964, pp. 191-206) listed the primary difficulties which must be overcome in establishing a regional water quality system, including institutional factors, data requirements, regional size, type of authorities, and proper allocation of costs and benefits.

Timmons (1967) also noted that in establishing water quality standards

> "...the setting of such standards involves economic analyses of costs and benefits of alternative uses and the identification and measurement of their respective incidences."

Data requirements were also noted:

> "In determining water quality standards by supply-demand units, it appears that much more information and analysis is needed including the technological, legal, and economic aspects."

In presenting the conservation view of the need for water quality management, Gabrielson (1965) was also concerned with technology:

> "Better laws and more vigorous enforcement can help greatly in reducing water pollution, but today's Great Society lacks the technological knowledge to prevent all water pollution."

In addition to these major problems of regulation, economics, financing, technology, data requirements, and regional planning needs, the operation and maintenance phase must not be neglected. Seidel (1967) especially stressed the need for competent operation of water pollution control facilities in the river basins, for without attention at this point the efforts expended in planning, engineering, education, and enforcement are wasted. He concluded that competent operation of the waste treatment system is the key to successful water resource management of water quality.

III. IDENTIFICATION AND EFFECTS OF POTENTIAL POLLUTANTS

A. General Classification of Water Polluting Substances

Every known substance which may enter or be found in surface waters, or in groundwaters, is considered to be a potential pollutant having the ability to affect the beneficial use of water (McKee and Wolf, 1963). Therefore, a comprehensive investigation of water quality should include each such substance. Because of the large number of substances known to mankind, only the more common and most publicized potential pollutants were collated by McKee and Wolf (1963). Over 800 substances were listed alphabetically, and summaries, threshold concentrations, and limiting values were given for most of them. The extensive general listing of potential pollutants was partially subdivided to direct specific attention to four categories: (1) biological pollutants, (2) radioactive substances, (3) pesticides, and (4) surface-active agents.

Biological pollutants were separated by McKee and Wolf to permit summaries to be made of the effects of living material, both plant and animal, upon water quality and subsequent beneficial use of water. Primary biological pollutants were noted to be those biota that man adds directly to water, e.g., enteric bacteria and viruses from domestic sewage. Corollary biological pollutants were noted to be those indigenous living organisms that interfere with any of the beneficial uses of water, either by natural existence and growth processes, or by stimulation from activities of man. Algal blooms were given as a characteristic example. Although the specific problem agent was not added directly to the water, the adverse effect may nonetheless be attributed to human activities and endeavors.

Two additional facets concerning biological substances may enter into water quality studies, according to McKee and Wolf (1963). First, the impact of pollutants upon the natural and/or desirable aquatic and marine life is used frequently to indicate the level or degree of pollution. Second, the role of living material is fundamental to the biochemical and biological stabilization of waste products.

The pesticide category included the many substances used to control objectionable insects, weeds, and probable other undesirable life or organisms. Surface-active agents originated with the introduction of detergents by the soap industry.

All of these water polluting substances were classified into eight general categories by the U.S. Public Health Service (U.S. Senate Select Committee, 1960e):

1. Sewage and other oxygen demanding wastes
2. Infectious agents
3. Plant nutrients
4. Organic chemical exotics
5. Other mineral and chemical substances
6. Sediments
7. Radioactive substances
8. Heat, or temperature effects

The biological pollutants category of McKee and Wolf (1963) is included in the first three items. In addition, the separate pesticide and surface-active categories are combined into the organic chemical exotics.

The most recent report regarding potential pollutants and water quality criteria was prepared by the National Technical Advisory Committee to the Secretary of the Interior (Federal Water Pollution Control Administration, 1968). Criteria were summarized for five general areas of beneficial water use: (1) recreation and esthetics, (2) fish, other aquatic life and wildlife, (3) public water supply, (4) agricultural (farmstead supply, livestock watering and irrigation) water supplies, and (5) industrial water supply requirements (steam generation, cooling, and production process). Recommendations for quality control of various potential pollutants were made to minimize any unreasonable interference with each beneficial use of water.

Because of the inclusive nature of the U.S.P.H.S. classification of water polluting substances into eight categories, this general breakdown will be used in pursuing a review of each, as these substances relate to the beneficial uses of water.

B. Sewage, Other Oxygen Demand Substances, and the Oxygen Resource

This category includes the traditional organic wastes which originate as domestic sewage and as residues from food processing industries. Thus, human fecal material as well as various plant and animal organic residues were included (U.S. Senate Select Committee, 1960e). The major elements in these organic wastes have been identified as carbon, oxygen, hydrogen, nitrogen, phosphorus, and sulfur, with about 60% of the total weight of solids in domestic sewage being organic and 40% being less-offensive inorganic substances (Babbitt and Baumann, 1958).

Theriault (1927), in a comprehensive review of the oxidation process as it was understood at that time, noted that laboratory studies of the rate of oxidation of polluted river water had been reported by 1870. It was soon recognized that the oxygen depletion was caused by microorganisms. Additional research (between 1895-1914 in Great Britain) into the biochemical nature of the oxidation process led to the test "dissolved oxygen absorbed in five days at 65 deg F." The standard determination for biochemical oxygen demand (BOD, 5-day, 20 deg C) evolved from this initial test, permitting quantitative measurement of the potential pollution in terms of the amount of oxygen required for stabilization of organic wastes by biological processes (Standard Methods, 1965).

These organic wastes, under desirable natural or artificial operating conditions and with a plentiful supply of oxygen, are oxidized to stable compounds by aerobic bacteria. In surface waters, the oxygen required for stabilization is taken from the dissolved oxygen normally present in the water under natural conditions. If the dissolved oxygen in a stream is reduced to zero by organic waste oxygen demands, anaerobic bacterial action begins, and the organic wastes are reduced slowly to inert materials in the absence of atmospheric oxygen. A septic, odorous condition can then occur, and a nuisance condition may prevail (Streeter and Phelps, 1925; Phelps, 1944; Senate Select Committee, 1960e; McKee and Wolf, 1963).

1. Carbonaceous and nitrogenous oxygen demands

The major component of the biological oxidation process was considered to be the demand for oxidizing organic carbonaceous material, as biological organisms utilized the oxidation process as a source of energy and materials for their general metabolism and new cell synthesis (Streeter and Phelps, 1925; Phelps, 1944; Theriault, 1927). This component was labeled the "first-stage" or "carbonaceous stage" of the oxidation process.

To permit evaluating the strength of both domestic sewage and the organic wastes from industrial processes on a common basis, the term "population equivalent" has been adopted (Babbitt and Baumann, 1958; U.S. Senate Select Committee, 1960e). For the carbonaceous demand, the commonly accepted value is 0.17 to 0.18 pound of oxygen (5-day, 20 deg C) required to stabilize the daily domestic wastes of one person. Adoption of this unit permitted the oxygen demand of both domestic sewage and industrial wastes of an organic nature to be expressed in terms of an equivalent population, at least for those industrial wastes which are amenable to the biological process of stabilization. The unit has been useful not only in allocation of costs for constructing and operating water pollution control plants, but also in expressing the total oxygen-demanding pollution loads placed upon the surface water resource. Projections of these loads have been made for the continental U.S.A., for the period 1960 through 2010 (U.S. Senate Select Committee, 1960e).

The second stage of oxidation was attributed by Adeney to a nitrogenous stage, for the progressive nitrification of organic and ammonia nitrogen found in domestic wastes to the nitrite and nitrate states (Phelps, 1944, p. 87). For raw sewage, Phelps stated:

> It is generally observed that these nitrifying reactions do not begin to assert themselves until the greater part, if not all, of the so-called carbonaceous material, and even of the more typical carbohydrate chains in protein material, have been oxidized.

Further,

> The distinct separation usually observed is attributed to the fact that the nitrifying bacteria are not normally present in large numbers and that there is a resultant lag period during which their numbers are building up sufficiently to give active nitrification.

It was concluded that

> ...it seems probable that the effect of organic matter during its active oxidation is to reduce the potential within the system below that necessary for the functioning of the nitrifying organisms. ...the drain upon the oxygen reserves reduces the potential to a level too low to permit nitrification.

But under certain conditions, Phelps (1944, pp. 86-87) considered that the reactions could proceed together, as was shown by Heukelekian (1942). Sawyer and Bradney (1946) found that effluents from water pollution control plants, especially those using trickling filters for secondary treatment, were in an active stage of nitrification. Laboratory analysis showed that nitrification was extensive and a large part of the effluent BOD was due to nitrogenous oxidation. This effect (1) influenced BOD studies and the results thereof, including evaluation of removal efficiencies of the carbonaceous waste load, and (2) indicated an additional oxygen demand for complete nitrification. The effect of nitrification upon stream behavior has since been evaluated quantitatively (Velz, 1947, 1949; Buswell and Pagano, 1952; Klein, 1962; Courchaine, 1963; Gannon, 1966; Purdy, 1966).

The oxygen demands of organic phosphorus wastes entering the ecosystem also were reported recently (Federal Water Pollution Control Administration, 1968). One milligram of phosphorus from an organic source requires about two mg of oxygen for complete oxidation. McKee and Wolf (1963) noted that the oxidized form was rapidly used by plants and converted into cell structures through photosynthetic action.

The levels of oxygen demanding substances and other potential pollutants found in raw domestic sewage and which are significant in water quality studies and pollution control were summarized by Babbitt and Baumann (1958). Values for strong, medium and weak sewages are shown in Table 1. The relative strength of a domestic waste will depend on the per capita water use and the amount of commercial and industrial activity in a municipality.

The oxygen demands of organic pollutants can reduce the dissolved oxygen in a stream sufficiently to affect other natural biological, aquatic and marine life which also is dependent for life upon dissolved oxygen. As a result, the relationship between dissolved oxygen and biochemical oxygen demand was recognized early as being fundamental to a study of stream pollution (Streeter and Phelps, 1925; Phelps, 1944; McKee and Wolf, 1963). Zones of water quality and biological activity were established for streams, applicable to reaches in which wastes were being discharged. Four zones in a stream in which self-purification was achieved were identified. From the clean water zone above a single point of waste discharge, the progressive zones in a downstream direction

Table 1. Typical values for characteristic potential pollutants found in raw sewage[a]

Potential pollutant	Amount of pollutant in mg/l for indicated sewage strength[b] Strong	Medium	Weak
Solids, total	1,000	500	200
Volatile	700	350	120
Fixed	300	150	80
Suspended solids	500	300	100
Volatile	400	250	70
Fixed	100	50	30
Dissolved solids	500	200	100
Volatile	300	100	50
Fixed	200	100	50
Settleable solids (ml/l)	12	8	4
Biochemical oxygen demand, 5-day, 20 deg C	300	200	100
Nitrogen, total	85	50	25
Organic	35	20	10
Free ammonia	50	30	15
Nitrites (RNO_2)	0.10	0.05	0.0
Nitrates (RNO_3)	0.40	0.20	0.10
Phosphates (PO_4)	35	25	15
Chlorides	175	100	15
Alkalinity (as $CaCO_3$)	200	100	50
Fats	40	20	0

[a]Source: Babbitt and Baumann (1958), Mackenthun (1965), and Middleton (1966).

[b]Except as noted.

were designated as zones of (1) degradation, (2) active decomposition, (3) recovery, and (4) clean water (Phelps, 1944; Babbitt and Baumann, 1958; Ingram, et al., 1966). The dissolved oxygen balance as well as the biota of flora and fauna vary from zone to zone, as illustrated empirically in a recent report by Ingram et al. (1966).

2. The oxygen resource and the stream environment

The amount of dissolved oxygen which clear water will absorb from the atmosphere varies at saturation from 14.65 mg/l at 0 deg C, to 9.02 mg/l at 20 deg C (68 deg F) and 7.44 mg/l at 30 deg C, for distilled water at an atmospheric pressure of 760 mm Hg. (sea level) (Committee on Sanitary Engineering Research, A.S.C.E., 1960). These values vary somewhat from those listed in Standard Methods (1965) and indicate the difficulty of obtaining accurate results for natural phenomena. Values at saturation must be reduced for increased elevations, may vary diurnally with local changes in barometric pressure, and must be reduced also for increased solids content. Diurnal fluctuations in dissolved oxygen levels may occur also as a result of the cycle of day-time photosynthesis and respiration (day and night) by algae, including supersaturation during the daytime phase (McKee and Wolf, 1963; Ingram et al., 1966). Reduced levels of dissolved oxygen can affect (temporally and spatially) the stream environment and the biota it contains.

a. Fish and other aquatic life The effects of oxygen demanding substances upon the fisheries habitat of surface waters have been studied by many investigators. Ellis (1937) concluded from field observations that a varied and bountiful population of fish existed in streams where the dissolved oxygen level did not drop below 5 mg/l. Moore (1942) reported on the effects of low levels of dissolved oxygen upon seven types of fish; pike, black bass, black crappie, common sunfish, perch, sunfish, and black bullheads. The species studied varied from cold water to warm water varieties. Minimum dissolved oxygen concentrations for fish survival (for at least 24 hr) varied from 6.0 to 3.3 mg/l (cold water to warm water species) in the summer with a median value of 4.2 mg/l. Winter minimum survival concentrations varied from 4.7 to 1.1 mg/l, with a median value of 3.1 mg/l. It was concluded that survival required an average dissolved oxygen level of 3 to 4 mg/l, winter to summer, respectively, although for cold water species the comparable values would be 5 to 6 mg/l. If median values dropped to 1.4 to 3.1 mg/l, death occurred within 24 hr.

Tarzwell (1958, 1966) has summarized the water quality requirements for aquatic life. In the latter summary he noted that although the dissolved oxygen requirements for several fishes have been reported, the requirements for other aquatic organisms is largely unknown, and oxygen relationships with temperature (synergistic effects) remain undetermined at the present time. Three categories of fisheries habitat were indicated by Tarzwell, (1) a cold water fisheries habitat (for salmon, trout, etc.), (2) a warm water well-rounded game fisheries habitat (for sunfish, bass, etc.), and (3) a warm water, rough, coarse food-fish habitat (for carp, buffalo, etc.). These three categories were included also in the recent comprehensive report of the Committee on Water Quality Criteria (FWPCA, 1968).

For cold water fisheries, Tarzwell (1966) recommended that the minimum dissolved oxygen permitted should be no lower than five mg/l. This minimum should be permitted for only a few hours in any daily period, and average daily values of at least 6 to 7 mg/l were suggested for satisfactory hatching and growth rates. For well-rounded warm water game fish populations, it was recommended that the minimum level of dissolved oxygen should not be lower than 4 mg/l for short periods of time, and average daily values of 5 mg/l or more were desirable. For the coarse food-fish population, minimum dissolved oxygen levels should not be lower than 3 mg/l at any time or place, and levels between 3 and 4 mg/l should not occur for more than a few hours in any 24-hr period. Tarzwell concluded that although specific fishes can tolerate and live in an inactive state at much lower dissolved oxygen levels, this was not a desirable situation. The recommended levels were necessary for (1) survival of the species, (2) establishment of a well-rounded biota, and (3) optimum production and harvest of a normal crop (Tarzwell, 1966).

The diurnal fluctuations of dissolved oxygen caused by temperature changes and the algae photosynthesis-respiration cycle were considered in the recommendations of the Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Commission (1955, 1956, 1960). For a well-rounded warm water fish population, the dissolved oxygen content of warm water fish habitats should be not less than 5 mg/l during at least 16 hr of any 24-hr period, and might be less than 5 mg/l for a period not to exceed 8 hr within any 24-hr period, but at no time should it be less than 3 mg/l. To sustain a coarse fish population, the dissolved oxygen concentration should be less than 5 mg/l for a period of not more than 8 hr out of any 24-hr period, but at no time should the concentration be lower than 2 mg/l.

In regard to aquatic life in general, the Committee on Water Quality Criteria (FWPCA, 1968) stated

> Most of the research concerning oxygen requirements for freshwater organisms deals with fish, but since fish depend upon other aquatic species for food and would not remain in an area with an inadequate food supply, it seems reasonable to assume that a requirement for fish would serve also for the rest of the community...... ....we must know ...the oxygen concentration that will permit an aquatic population to thrive...

The recommendations for dissolved oxygen were not as specific, in terms of diurnal fluctuations and categories, as those previously noted:

> ...the following environmental conditions are considered essential for maintaining native populations of fish and other aquatic life:
>
> (1) For a diversified warm-water biota, including game fish, daily DO concentration should be above 5 mg/l, assuming that there are normal seasonal and daily variations above this concentration. Under extreme conditions, however, and with the same stipulation for seasonal and daily fluctuations, the DO may range between 5 mg/l and 4 mg/l for short periods of time, provided that the water quality is favorable in all other respects.
>
> .....These requirements should apply to all waters except administratively established mixing zones... In streams, there must be no blocks to migration and there must be adequate and safe passageways for migrating forms. These zones of passage must be extensive enough so that the majority of plankton and other drifting organisms are protected.
>
> (2) For the cold water biota, it is desirable that DO concentrations be at or near saturation. This is especially important in spawning areas where DO levels must not be below 7 mg/l at any time. For good growth and the general well-being of trout, salmon, and other species of the biota, DO concentrations should not be below 6 mg/l. Under extreme conditions they may range between 6 and 5 mg/l for short periods provided that the water quality is favorable and normal daily and seasonal fluctuations occur. In large streams that have some stratification or that serve principally as migratory

> routes, DO levels may be as low as 5 mg/l for periods up to 6 hours, but should never be below 4 mg/l at any time or place.

Data from these several sources are summarized in Table 2. As noted by these investigators, greater values than the minimum survival levels are needed for normal growth and activity, and to permit optimum harvest of aquatic life. In addition, a synergistic effect has been observed between dissolved oxygen levels and temperature, the latter affecting the rate at which fish utilize oxygen. Higher temperatures required higher oxygen levels for survival, with the converse also being true. Differentiation between the summer and winter seasons thus appears justified. Similar synergistic effects have been noted with toxic substances at low oxygen levels.

b. Other beneficial water uses Dissolved oxygen requirements for uses other than for supporting aquatic life are not as quantitative. For recreation, the Report of the Committee on Water Quality Criteria (FWPCA, 1968) stated

> Surface waters, with specific and limited exceptions, should be of such quality as to provide for the enjoyment of recreation activities based upon the utilization of fishes, waterfowl, and other forms of life, without reference to official designation of use......

Dissolved oxygen levels greater than 3-4 mg/l at public water supply intakes were assigned as permissible criteria, primarily to reflect an indication of pollution if lower values were observed. The presence of fish in a potential source of water was also noted to be an indicator of acceptability for water supply purposes from an esthetic viewpoint. Oxygen levels have not been a problem to industry which has usually accepted the quality received. In some processes including boiler feed

Table 2. Summary of recommended dissolved oxygen levels[a] for fish and other aquatic life

Category of fisheries habitat	Dissolved oxygen level in mg/l: Summer season: Average daily	Summer season: Maximum period of day	Summer season: Minimum, absolute or minimum period, 8 of 24 hr	Winter survival (or other extreme conditions): Average daily	Winter survival (or other extreme conditions): Minimum, absolute or minimum period, 8 or 24 hr
1. Cold water fisheries	6-7 or more	6 or more	6 or 7[b]	5-6 or more	5
2. Warm water, well-rounded, game fisheries	5 or more	5 or more	4	3-4 or more	3
3. Warm water, rough, coarse, food-fish	5 or more	5 or more	3	3-4 or more	2

[a]Sources: Ellis (1937), Moore (1942), Tarzwell (1958, 1966), Aquatic Life Advisory Committee, ORSANCO (1955, 1956, 1960), and FWPCA (1968).

[b]Minimum for spawning areas.

water, low dissolved oxygen levels are desired (McKee and Wolf, 1963; FWPCA, 1968).

C. Infectious Agents

1. Identification and analysis

Infectious agents are pathogenic entities or disease causing organisms which may be discharged into surface or ground waters from a multitude of sources. The potential pathogenicity of receiving waters has been summarized by Gloyna (1966, p. 480). The list of pathogenic entities included viruses, protozoa, and bacteria that cause waterborne diseases experienced today:

1. Viruses
   a. Poliomyelitis
   b. Infectious hepatitis
   c. Adenovirus — upper respiratory and ocular diseases
   d. Epidemic gastroenteritis
   e. Coxsackie
2. Protozoa
   a. Endamoebic histolytica — amebic dysentery
3. Bacteria
   a. Salmonella — typhoid and paratyphoid
   b. Shigella — dysentery
   c. Spirillum cholera — cholera
   d. Acid-fast bacteria — tuberculosis

The general relationship between infectious agents and diseases is well known (Gainey and Lord, 1952; U.S. Senate Select Committee, 1960e; McKee and Wolf, 1963). Infectious diseases may result from ingesting these organisms directly through drinking untreated polluted water or such water insufficiently treated, or in food products processed with such water. They may also be ingested indirectly through surface contact during recreational or other activities. Although effective waste treatment followed by disinfection can reduce markedly the number of disease organisms in waste effluents, a portion of each kind present in the raw sewage may still be present in the effluent. The concentration of the surviving pathogens and their persistence in receiving waters are dependent upon several factors, including the exposure to sunlight, degree of dilution, and the physical, chemical, and biological characteristics of the receiving stream.

Direct examination or analysis of water for the presence of each specific pathogen is expensive, slow, and unwieldy for routine control purposes (McKee and Wolf, 1963, p. 308; FWPCA, 1968, p. 11). Characteristically, therefore, water is analyzed for evidence of fecal contamination, and when such indication is discovered the assumption is made that the water is potentially dangerous. The indicator group of organisms of diverse origin most commonly used is the coliform group, which includes "all aerobic and facultative anaerobic, Gram-negative, nonspore forming, rod shaped bacteria that ferment lactose with gas formation within 48 hours at 35 degrees C" (Gainey and Lord, 1952; McKee and Wolf, 1963; Standard Methods, 1965). The best known strains within this group are (1) Escherichia coli, usually but not always of fecal origin, and (2) intermediate strains including *Aerobacter aerogenes*, usually of soil, vegetable, or other nonfecal origin. Two laboratory methods have been used in surveillance programs, the multiple tube fermentation and the membrane filter procedures (McKee and Wolf, 1963; FWPCA, 1968). In the first, the laboratory test and interpretation of results involves three successive phases — (1) a presumptive test, (2) a confirmed test, and (3) a completed test. The results thereof are either positive or negative, with an additional doubtful category for the first two steps. By using a series of dilutions, the density of the coliform population is estimated and reported normally in terms of the Most Probable Number (MPN) per 100 ml (Gainey and Lord, 1952; Standard Methods, 1965).

Coliform organisms may reach surface waters from several sources, including (1) excretions from humans, animals, amphibians, and birds, (2) direct surface runoff, and (3) multiplication of nonfecal forms on fibrous and vegetable organic substances found in water (McKee and Wolf, 1963). Large numbers have been found in raw wastes, with human feces averaging almost two billion per capita per day (Geldreich et al., 1962). These multiply rapidly, and raw domestic sewage may contain from about 20 to over 100 billion coliform per capita per day, depending upon the season (Kittrell and Furfari, 1963). In conventional methods of waste treatment, the numbers are reduced considerably. Below waste effluent outfalls in the absence of disinfection, it has been observed that coliform organisms have increased in numbers during the biological oxidation phase, with a maximum density occurring within 10 to 15 hr. Counts of 4 to 8 times the number discharged have been recorded, but after maximum density was reached, rapid destruction of the coliforms occurred (Kittrell and Furfari, 1963). A death rate of over 99% has been recorded within a period of 4 to 8 days in the summer. In winter periods, reductions of about 70 to 90% after 2 days and 87 to 95% after 4 days have been noted (Berg et al., 1966; U.S. Senate Select Committee, 1960e). The survival of bacteria in surface waters has depended on a number of factors, including temperature, pH, sunlight, adsorption phenomena, nutrient levels for continued growth, predators, rainfall and runoff, stream characteristics, salinity, and the presence of other synergistic or antagonistic pollutants (Berg et al., 1966).

Because the use of total coliform organisms in sanitary evaluation does not prove fecal pollution, it has been recommended that only fecal coliforms be used as the indicator organisms and in selection of criteria (FWPCA, 1968). Other potential indicator organisms have been suggested to replace or supplement the coliform tests. The use of fecal streptococci, such as the enterococcus group (Streptococcus faecalis), as a more specific indicator also has been suggested. These groups of fecal organisms do not multiply in surface waters and rarely occur in surface soils or on vegetation (McKee and Wolf, 1963). However, the coliform test still remains the most practicable (McKee and Wolf, 1963; FWPCA, 1968). In addition, McKee and Wolf concluded that one should not "give undue weight to the results of the bacterial tests alone" but that "the interpretation of quality of a water should be based on the combined findings of the bacterial examination and a sanitary survey of the area in question ....."

Pathogenic bacteria and the viruses are much more difficult to detect in or isolate from water than the coliforms (Berg et al., 1966). Survival rates usually exceed those of bacteria, with 20 to 30 days being required for 99.9% reduction of some viruses in polluted river studies (Clarke et al., 1956). Greater chlorine residuals are needed for viruses than for bacteria (McKee and Wolf, 1963). Therefore, it must be assumed that the absence of coliforms in a surface water does not necessarily preclude the presence of viruses (Berg et al., 1966; Baumann, 1967). The overall problem remains one of easily isolating specific viruses, pathogenic bacteria and other infectious agents, and in determining the minimum infective dose (MID) and related infection rates for specific diseases, thus permitting limiting levels of concentrations to be recommended.

2. Effect upon beneficial water uses

Infectious agents have been of the most serious concern to water supply purveyors. Using the coliform group of organisms, they have recommended limiting concentrations for surface sources of water supply. Four categories were established for drinking water standards by the U.S. Public Health Service (U.S. Department of Health, Education and Welfare, 1962).

> Group I. Water requiring no treatment. Limited to underground waters not subject to pollution.
>
> Group II. Water requiring simple chlorination or its equivalent. Includes both underground and surface waters subject to a low degree of potential pollution. Coliform bacteria content should average no more than 50 per 100 ml in any month.
>
> Group III. Waters requiring complete rapid sand filtration, or its equivalent, together with continuous post-chlorination. Coliform bacteria content to average

not more than 5,000 per 100 ml in any one month, and not to exceed that number in more than 20 percent of the monthly samples.

Group IV. Waters requiring auxiliary treatment (pre-sedimentation and/or prechlorination) in addition to complete filtration treatment and post-chlorination. Coliform bacteria content not to exceed values given for Group III, but 5 percent of monthly samples permitted to be as high as 20,000 per 100 ml.

More recently, the Committee on Water Quality Criteria (FWPCA, 1968) recommended the use of two coliform groups. These are summarized in Table 3. These limits were based on monthly averages, using an adequate number of samples (five minimum). It was suggested that total coliform limits could be relaxed if the fecal coliform concentrations did not exceed the specified limits. Industrial water users including those in the food canning industry and in carbonated beverage preparation normally have accepted the drinking water standards of the U.S. Public Health Service, but a need to be even more stringent in food handling processes has been noted (McKee and Wolf, 1963).

Table 3. Recommendations for coliform levels in surface sources of public water supply[a]

Type	Limiting concentration, per 100 ml Permissible level	More desirable level
1. Coliform organisms	10,000	Less than 100
2. Fecal coliforms	2,000	Less than 20

[a]Source: FWPCA (1968).

Clean water is desired also for agricultural livestock water supply, but it was recently reported that "total microbial elimination in natural water appears to be an impractical procedure for man, let alone livestock" (FWPCA, 1968, p. 139). Therefore, the status of the aquatic habitat was selected to serve as a general indicator of the quality for agricultural purposes. In addition, use of polluted water or sewage effluents for irrigation must be carefully controlled (McKee and Wolf, 1963) with a need for specific controls recognized in vegetable production for human consumption (Skulte, 1956).

Both commercial and sport fisheries have been concerned with infectious agents in the coastal shellfish environment, particularly for oysters, clams and mussels (McKee and Wolf, 1963). Careful control is exercised over harvest areas since the shellfish can ingest polluted water and transmit intestinal disease organisms during consumption. On inland streams, harvest of rough fish in the vicinity of sewer outfalls has also presented a problem, both in taste and odor, and in accidental contamination during handling, cleaning, preparation, etc.

Water recreation specialists usually have divided the recreation use into two groups. The first group includes activities involving body contact with the water, such as wading, swimming, bathing, surfing, and water skiing, that carry a potential for ingesting polluted water. The second group consists of those in which only casual contact if any can normally be expected, such as fishing and picnicking (Water Resources Policy Commission, 1950). More recently these have been grouped into primary contact and secondary contact recreation uses (FWPCA, 1968). Primary contact recreation involves body contact with water having in addition "considerable risk of ingesting water in quantities sufficient to pose a significant health hazard." Secondary contact recreation activities do not involve significant risk of ingestion of infectious agents. Because considerable difficulty has been experienced in establishing definitive relationships between epidemiological data of disease outbreaks and levels of coliform bacteria, development of precise limits has not been possible to date (McKee and Wolf, 1963; Van Morgan, 1966).

A swimming and bathing classification, Table 4 (McKee and Wolf, 1963, p. 315), was suggested for use in Connecticut to indicate the relative position of certain waters used for bathing, subject however to additional study. The first three classes, with the same limits, have been used in recreation areas in the reservoir system of the Tennessee Valley Authority (Van Morgan, 1966), where the coliform counts are used in conjunction with sanitary surveys to minimize the probable risk to the health of swimmers in designated beach areas.

Table 4. A suggested classification of bathing waters based upon bacteriological analysis[a]

Class	Acceptability	Average coliform count, MPN per 100 ml
A	Good	0 – 50
B	Doubtful	51 – 500
C	Poor	501 – 1,000
D	Very poor	Over 1,000

[a]Source: McKee and Wolf (1963).

For primary and secondary recreation activities, the fecal coliform levels listed in Table 5 were recommended by the Committee on Water

Table 5. Recommended values for fecal coliform limits in recreation activities[a]

Class	Fecal coliform limits, per 100 ml Average of all samples	Maximum of all samples
1. Primary contact	200	400
2. Secondary contact		
a. Enhancement status	1,000	2,000
b. General use areas	2,000	4,000

[a]Source: FWPCA (1968).

Quality Criteria (FWPCA, 1968). The enhancement status was assigned to areas definitely designated for water recreation use, in which constructed facilities encouraged contact with the water. The general use category applied to those areas where the water is used in an esthetic sense, as a background concept for picnicking, etc.

D. Plant Nutrients and Plant Growths

1. The role of nutrients

Plants and animals in the aquatic environment live in a complex world and exist in a state of dynamic balance in which change and interrelationships are inherent. Certain levels of each are desirable and serve a worthwhile purpose in maintaining an ecological system favorable to recreation, fish, wildlife, and other related beneficial uses of water. However, beyond this point they have developed a nuisance value (McKee and Wolf, 1963). Overabundance of algae (algal blooms) and weed growths has led to (1) eutrofication of lakes, (2) adverse effects upon the physical water characteristics favorable for a balanced aquatic environment, (3) secondary pollution caused by excessive amounts of dying plants, (4) water treatment and taste and odor problems, and (5) certain toxic effects (direct poisoning) and related ailments to animal life, including humans (McKee and Wolf, 1963; Mackenthun, 1965).

Plant nutrients are mineral substances, primarily in solution, which are necessary elements in the metabolism of aquatic plant life. The growth of algae and water weeds is stimulated by the presence of large amounts of these nutrients, and nitrogen and phosphorus are noted to be the two main elements in this category. Sources of increased amounts today include domestic sewage, certain industrial wastes, and seepage and runoff from agricultural lands upon which chemical fertilizers are used in ever-increasing quantities (U.S. Senate Select Committee, 1960e). Trace elements have also played an important role in sustaining rapid growth of algae and other aquatic plants (Tarzwell, 1966).

2. Water weeds and algae

Water weeds are classified as those aquatic growths having a root system and which are attached to the stream boundary (McKee and Wolf, 1963), although a few free-floating species also exist. Except for the free-floating group, water weeds are divided into two major groups, emergent and submerged. However, Otto and Bartley (1965) recognized three distinct groups of aquatic weeds, submersed, floating, and emersed.

Algal forms are classified into a four-part system by (Palmer and Ingram, 1955; Palmer, 1958), based upon the oxygen consuming or oxygen producing characteristics of the algae. These are (1) blue-green algae, (2) green algae, (3) diatoms, and (4) flagellates. Two distinct groups also have been recognized according to habitat, (1) phytoplankton, or the suspended population, and (2) attached varieties or standing crop, including most diatoms and the filamentous species of the other three types (Phelps, 1944; Prescott, 1964). Fair et al. (1968) also list these four families in a comprehensive treatment of aquatic biology.

One of the most important effects of algae upon stream water quality is upon the dissolved oxygen resource of the stream. The general process of plant growth has been explained by several authors (Sawyer, 1960; McKinney, 1962; McKee and Wolf, 1963; Ingram et al., 1966; Fair et al., 1968; FWPCA, 1968). Algae produce oxygen during the daylight photosynthesis period during which dehydrogenation of water molecules occurs, subsequently combining with carbon dioxide to form simple sugars for algal growth and metabolism. It is illustrated generally by the biochemical reaction:

$$6\ CO_2 + 6\ H_2O \underset{\text{Chlorophyll}}{\overset{\text{Sunlight}}{\longleftrightarrow}} C_6H_{12}O_2 + 6\ O_2\ .$$

In the continual respiration phase, the reverse reaction occurs with energy being obtained as oxygen is consumed and carbon dioxide produced. The amount of oxygen produced during daylight hours through photosynthesis is much greater than the respiration requirements on cloudy days or at night. Therefore, the daytime photosynthesis and nighttime respiration phases may result diurnally in oxygen supersaturation in the daytime and oxygen depletion at night (Phelps, 1944; Lackey, 1958; Ingram et al., 1966). Values of supersaturation as high as 300% have been reported during daylight hours, with nighttime depletion being as low as 50% of saturation or less (Phelps, 1944; McKee and Wolf, 1963). Nuisance growths have an additional adverse effect upon the stream environment. Dead algal and aquatic weed growths in turn exert a biochemical oxygen demand on the stream, caused by the biological life which uses the organic material for food, in a repetition of the carbon cycle.

3. The role of nitrogen and phosphorus

The role of nitrogen and phosphorus as the primary nutrients in creating undesirable conditions in surface waters has been investigated in depth in recent years. A comprehensive bibliography was prepared by Mackenthun (1965). Nitrogen may gain access to water in solution as the result of nitrogen fixation and absorption from the air, ammonia from rainfall or rainout, organic nitrogen from decomposing plants and animals, land drainage including seepage and runoff, and wastes and waste effluents. In solution, the element may exist as organic nitrogen, or as the ammonium ion (NH_4^+), the nitrite ion (NO_2^-), or the nitrate ion (NO_3^-). Progressive oxidation through bacterial action converts the more reduced forms to nitrates:

$$\text{Protein (Organic N)} \xrightarrow{\text{bacteria}} NH_3 + \text{Byproducts}$$

$$NH_3 + \frac{3}{2} O_2 \xrightarrow{\text{bacteria}} NO_2^- + H^+ + H_2O$$

$$2\ NO_2^- + O_2 \xrightarrow{\text{bacteria}} 2\ NO_3^- .$$

The conversion to ammonia can occur under either aerobic or anaerobic conditions, but the latter two conversions require aerobic conditions and the action of the nitrite and nitrate formers (Nitrosomonas and Nitrobacter). Some bacteria may reduce nitrates and nitrites under anaerobic conditions (Sawyer, 1960). The oxidation reactions representing the net stoichiometric changes indicate that 4.569 mg/l of oxygen are required theoretically to convert one mg/l of ammonia occurring as N-Nitrogen to the nitrate form.

The principal nitrogen constituents in raw domestic sewage are organic nitrogen (proteins) and ammonia (see Table 1), with secondary treatment effluents being in the nitrification stage under certain conditions. Also, various forms of algae are facultative, and may use any of the forms of nitrogen, including ammonia (Sawyer, 1960; Mackenthun, 1965).

The role of phosphorus has been summarized by Mackenthun (1965). Phosphorus occurs naturally in rocks and soils as calcium phosphate, $Ca_3(PO_4)_2$. Being only sparingly soluble, only small amounts are brought into solution by the leaching and weathering process. In natural waters, within the normal range of pH, phosphorus exists in the secondary form, $CaHPO_4$. The element is necessary in biological life processes, and is converted into organic phosphate in the biomass. In the absence of human influence, concentrations in water are reportedly very low (Mackenthun, 1965, p. 106).

Domestic sewage and certain industrial wastes are known to contain large amounts of phosphorus as compared with natural waters. Organic phosphorus in human wastes and the simple and complex phosphates found in synthetic detergents have been found to be the principal contributors (McKee and Wolf, 1963; Mackenthun, 1965). Phosphate levels in raw sewage have ranged from 15 to 35 mg/l of total phosphorus as $PO_4^{=}$ (Middelton, 1966), or 5 to 11 mg/l as phosphorus. These levels provide an abundant supply of soluble phosphorus leading to the development of nuisance biological growths.

The relative concentration of nitrogen and available phosphorus below which algal growth and aquatic weeds will not become a nuisance, has been reported by several investigators (Chu, 1943; Sawyer, 1952; Mackenthun, 1965). A value of 0.01 mg/l of inorganic phosphorus was suggested by Sawyer as being the maximum concentration that could be permitted without danger of supporting undesirable growths. Further, optimal nitrogen-phosphorus ratios for production of algal blooms ranged from 15 to 18 to one for some algae, and of 30 to one for others. Chu (1943) reported lower limits of 0.02 to about 0.09 mg/l for phosphorus, 0.3 to 1.3 for nitrate nitrogen, and 2.6 to 5.3 mg/l for ammonia nitrogen, below which no problems were noted. Other studies have indicated that if waste discharges increased the levels of inorganic phosphorus and nitrogen above 0.01 to 0.015 mg/l and 0.3 mg/l, respectively, at the start of the growing season, nuisance blooms of algae could be expected (Ingram and Towne, 1959; Lackey, 1961). Phosphorus levels of 0.012 to 0.041 mg/l caused nuisance conditions in a Connecticut reservoir (Benoit and Curry, 1961), yet 0.200 mg/l has not caused problems of aquatic growths for some public water supplies (FWPCA, 1968). The increase in domestic sewage phosphate levels through the years, as the use of detergents and water softening agents were increasing, was summarized by Engelbrecht and Morgan (1959). Physical, chemical and biological removal of these plant nutrients from waste effluents prior to discharge has been the subject of additional research (Weber and Atkins, 1966; Schaeffer, 1966; McKinney, 1962, 1966).

4. Ammonia as a toxic compound

Ammonia nitrogen, in addition to being a plant nutrient, is toxic to fish and other aquatic life (McKee and Wolf, 1963). Increasing ammonia concentrations decrease the ability of the fish hemoglobin to combine with oxygen, and the fish suffocate. Unpolluted rivers generally have ammonia concentrations less than 0.2 mg/l as N-Nitrogen with little problem of toxicity.

The relationship of ammonia, pH, carbon dioxide and dissolved oxygen has been found to be important in determining toxicity limits (McKee and Wolf, 1963). Ammonia is soluble in water, forming ammonium hydroxide. The dissociation equations are

$$NH_3 + H_2O \rightleftharpoons NH_4OH \rightleftharpoons NH_4^+ + OH^- .$$

For the range of pH commonly experienced in surface waters, 6 to 8 or more, most of the ammonia in water is known to be in the form of the ammonium ion (McKee and Wolf, 1963). High values of pH accompanied by low dissolved oxygen values are synergistic and greatly increase the toxicity of ammonia to fish.

McKee and Wolf (1963) also summarized the results of several investigations of the levels of ammonia toxic to fish. Concentrations of ammonium hydroxide above 20 to 30 mg/l (8 to 12 mg/l N-Nitrogen) have proven lethal to both rough fish and trout within a period of 24 hr. Concentrations less than about 10 mg/l (4 mg/l N-Nitrogen) have not proven lethal to suckers, shiners, and carp in 24 hr, but were lethal to goldfish and trout. In one study, trout appeared to be the most sensitive of the species, being affected by less than 1.0 mg/l, as ammonia. Ellis (1937) indicated that concentrations of 2.5 mg/l of ammonia (2.0 mg/l as N-Nitrogen) have been considered harmful in the pH range of 7.4 to 8.5.

5. Nutrient limits for beneficial water uses

Several nutrient limit guidelines to avoid and prevent nuisance growths which can adversely affect all the beneficial uses of water were recently reported (FWPCA, 1968). Total phosphorus was considered to be the reservoir from which the available phosphorus is supplied to the aquatic environment, and was considered to be the governing substance. A desirable guideline level was stated to be, for rivers, no more than 0.100 mg/l (P-Phosphorus), and where streams discharge into lakes, no more than 0.050 mg/l. An N:P ratio of 10:1 was expressed to represent normal conditions in a balanced ecological environment, and it was recommended that this guideline should not be changed appreciably.

Nitrites and nitrates have been of more concern in public water supplies than ammonia (U.S. Department of Health, Education and Welfare, 1962). The Committee on Water Quality Criteria added ammonia to the other two categories, and recommended guidelines of permissible levels for water supply sources as 0.5 mg/l (N-Nitrogen) for ammonia, and 10 mg/l (N-Nitrogen) for both nitrites and nitrates. More desirable criteria designated a maximum level of 0.01 for ammonia and a virtually absent designation for the latter two (FWPCA, 1968). Because it believed that much of the experimental work in aquatic life studies with ammonia compounds was not considered usable, the Committee recommended that permissible concentrations of ammonia should be evaluated only after using the flow-through bioassay technique.

E. Organic and Related Chemical Exotics

1. Identification of specific pollutants

Organic chemicals have widespread use today and include substances such as household and laundry detergents and agricultural insecticides, pesticides, and herbicides (weed killers). Many of these have been developed since World War II (U.S. Senate Select Committee, 1960e). This group was presented in the compilation of McKee and Wolf (1963) in two sections, (1) pesticides, and (2) surface active agents. The common pesticidal chemicals were divided chemically into three general sub-areas, (1) inorganics, (2) synthetic organics, and (3) natural organics.

Inorganic chemicals reported include the arsenicals, mercurials, borates, and fluorides. Synthetic organics include the chlorinated hydrocarbons, organic phosphates and thiocarbamates. Natural organics include rotenone, pyrethrum and nicotine (Pressman, 1963). If classified by their biological usefulness, then terms such as algicides, acaricides, fungicides, herbicides, insecticides, etc., were assigned. These chemicals have the potential of gaining access to ground and surface waters through direct application to the water, through infiltration and percolation, from direct surface runoff from treated areas, and/or through wind drift during application.

The surface-active agents include soaps, detergents, emulsifiers, wetting agents and penetrants. Three major divisions were selected by Pressman (1963) in classifying and discussing the surface-active agents, (1) anionic, (2) cationic, and (3) nonionic. The anionic agents ionize so that the major part of the molecule is the anion, and include the sulfates and sulfonates. Cationic agents ionize with the major portion of the molecule being the cation, and these agents include substituted ammonium compounds and cyclic quaternary ammonium compounds. Nonionic compounds do not ionize when dissolved in water. This latter category includes the polyethylene glycol fatty acid esters and ethers.

Fish kills have been one of the primary results of pesticide pollution and the magnitude of the problem has been summarized in several reports (Pressman, 1963; Tarzwell, 1966; FWPCA, 1968). Many of the pesticides are highly toxic to fish, with very low lethal concentrations. Toxicity results are reported usually in terms of the median tolerance limit, TL_m, the concentration of the substance fatal to 50% of the specific biological test specimens for a designated time period. Aldrin, for example, has been identified in some river fish kills. Toxicity studies in the laboratory showed that the 10-day TL_m for goldfish was 0.02 mg/l (Doudoroff and Katz, 1953). Some fish reportedly were killed with concentrations as low as 0.01 mg/l. DDT was found to be lethal at 0.003 mg/l (3 μg/l) in a 30-day study (Tarzwell, 1966).

The health effect of sublethal dosages of organic chemicals upon humans has been of even greater concern (U.S. Senate Committee, 1960e). The effect of long-term ingestion of organic chemicals by humans through water or through food sources of aquatic nature, such as fish, is not yet known. Proper dosage and careful application of these substances were emphasized by several public groups (U.S. Senate Select Committee, 1960e; National Academy of Sciences, 1966b).

Synthetic detergents may pollute water in several ways, as summarized by Patton (1963). They have resisted biological breakdown in secondary sewage treatment processes and were not metabolized rapidly in river waters or in groundwater. The major effect noted upon fish was damage inflicted upon the gills affecting the transfer of oxygen. Toxic effects have not been substantiated at concentrations encountered in most surface waters in the United States, although Patton concluded that long-term ingestion effects have not been studied. Synthetic detergents have caused serious problems in both waste treatment and subsequent downstream water treatment facilities. Foaming, turbidity, interferences with coagulation, and production of taste and odor were problems summarized by Patton (1963). Both humans and animals have refused to drink such polluted waters, primarily from the taste and odor aspect and not because of an immediate health problem.

The nonbiodegradable alkyl benzene sulfonate (ABS) in household synthetic detergents was replaced with the biodegradable linear alkyl sulfonate (LAS) by the detergent industry in recent years. As discussed by Cleary (1967), this solved the immediate problem of foaming in treatment plants, and in receiving waters. Quantitative limits have now been suggested for both (FWPCA, 1968), to avoid adverse and toxic effects upon aquatic life.

2. Tolerance limits

Zero tolerances for many pesticides were mentioned by Pressman (1963) for food products. Because of lack of knowledge and of simple analytical techniques for confirming and quantitatively evaluating these chemicals, official limits for organic pesticides in water have not been established in the United States (U.S. Department of Health, Education and Welfare, 1962). However, the possibility of introducing tolerance limits above "the lowest concentration detectable analytically" was discussed by Morris (1967). Such measurable tolerance limits have now been recommended by the Committee on Water Quality Criteria (FWPCA, 1968).

Permissible criteria for water supply sources and aquatic life which have now been formulated include fixed maximum levels or 48-hr TL_m values with an added recommendation to limit in-stream levels to a percentage of the TL_m value. For many of the organic chemicals, permissible levels are measured and expressed in terms of micrograms per liter (μg/l). More desirable criteria, for water supply sources, require that these substances be virtually or totally absent. It was especially recommended that chlorinated hydrocarbon insecticides not be used in the vicinity of surface waters and the related aquatic environment. For the other chemical pesticides, application factors varied from 1/10 to 1/100 of the 48-hr TL_m values. Several extensive summary tables present both the many chemicals in use and the various organisms for which TL_m levels have been reported (FWPCA, 1968, pp. 20, 62, 64, 65, 83, 125, 158, 159).

F. Other Mineral and Chemical Substances

1. Salts, acids and industrial chemicals

A number of miscellaneous and ordinary mineral and chemical substances are discharged as wastes or residues from various mining and industrial processes, or originate from certain natural geologic formations. These have been subdivided into three categories, (1) salts, (2) acids, and (3) other industrial chemicals (U.S. Senate Select Committee, 1960e). A heavy metals category has also been recognized, due to synergistic effects of the various metals contained in the group (McKee and Wolf, 1963; FWPCA, 1968).

Pollution from salts, dissolved from natural deposits, was noted to be a serious problem in many arid regions of the western United States (U.S. Senate Select Committee, 1960e). Excessive salt concentration during drought periods has frequently rendered river water unsuitable, as a source of water supply. Industrial salt pollution has occurred from brine discharged as a residue of oil drilling and pumping operations. Agricultural salt pollution has occurred in certain irrigated river valleys from return flows from irrigation as heavy concentrations of salts were leached from the soil (Water Resources Policy Commission, 1950; U.S. Senate Select Committee, 1960).

Several summaries have been made of the effect of acid wastes upon the pH levels of the receiving stream (U.S. Senate Select Committee, 1960; Cleary, 1967). Industrial plant wastes may contain acids, but the most extensive source of acid as a pollutant was reported to be seepage and drainage from coal mines. Sulfur bearing minerals, water and air combine to cause the acid-mine problem, and discharge occurs from unsealed mines or as mine drainage from operating mines of either the shaft or strip type. These problems have been confined mostly to the more humid regions of the United States, east of the Mississippi River. It has been estimated that over 90% of the acid mine drainage occurs in the Ohio River basin, but other Appalachian streams as well as tributaries of the Mississippi River in Illinois and other midwestern states are included in the problem area.

Water quality deterioration in streams has resulted from the acid waste problem, due to changes in pH, increased hardness and mineral content. Treatment for subsequent water uses is more difficult and expensive, corrosion of structures occurs, recreation values are reduced or eliminated, and biological and other aquatic life can be altered or destroyed (U.S. Senate Select Committee, 1960e). Ellis (1937) reported that the pH values of most inland waters containing fish range between 6.7 and 8.6, with extremes of 6.3 to 9.0. McKee and Wolf (1963) summarized the limiting pH values obtained through research studies, and showed that the overall range of tolerance extended from 4 to 10, with a desirable range for optimum growth of 6.5 to 8.4. It also was noted that algae and plankton were destroyed by values above 8.4, and below a pH of 5.0 specialized flora and fauna developed. Synergistic and antagonistic effects with other potential pollutants were considered important, and several studies showed that with previous acclimatization stream biota could develop a considerable tolerance for either low or high pH levels.

Other industrial chemical wastes of typical inorganic compounds can deteriorate water quality. The heavy metals group includes arsenic, barium, cadmium, chromium (hexavalent and trivalent), copper, lead, mercury, nickel, selenium, silver, boron, manganese, uranyl ion, and zinc as the principal substances for which specific levels need to be recommended for surface waters.

Other chemical constituents having an observable effect upon the stream environment include cyanides, chlorides, sulfides, and other substances. The ammonia-ammonium compounds were discussed previously, due to their additional effect upon the oxygen resource and as plant nutrients. The heavy metals group has been of special concern because (1) normal water supply treatment methods do little or nothing to remove them, (2) they pose an actual or potential hazard to humans and other animals due to adverse physiological effects, and (3) in the stream environment they are stable, conservative substances that persist spatially and temporally with a toxic or "poisonous" effect upon the stream biota (McKee and Wolf, 1963; Tarzwell, 1966; FWPCA, 1968). Many of the substances in the heavy metals group, in the organic chemical exotics, and including plant nutrients and oxygen demanding wastes are a part of the industrial waste problem, Therefore, they frequently have been considered as a separate category, industrial wastes (U.S. Senate Select Committee, 1960e, 1960j; Eckenfelder, 1966).

2. Criteria for limiting concentrations

Recommended surface water criteria for most of these substances are included in Table 6 (U.S. Department of Health, Education and Welfare,

Table 6. Recommended surface water criteria for selected beneficial uses of water[a]

Constituent or characteristic	Maximum level to be permitted as desirable criteria for designated water use, in mg/l: Water supply[b]	Recreation and aquatic life[c]
Arsenic	0.05	
Boron	1.0	
Barium	1.0	
Cadmium	0.01	1/30 96-hr TL_m
Chromium, hexavalent	0.05	0.02
Copper	1.0	1/10 96-hr TL_m
Lead	0.05	
Manganese	0.05	
Mercury		Perform bioassay
Nickel		Perform bioassay
Selenium	0.01	
Silver	0.05	
Uranyl ion	5.0	
Zinc	5.0	1/100 96-hr TL_m
Heavy metals as a group		1/100 96-hr TL_m
Cyanide	0.2	Perform bioassay
Ammonia, as N	0.5	1/20 96-hr TL_m
Chloride	250.	
Fluoride	0.8 – 1.7	
Iron	0.3	
Nitrate, as N	10.	
Sulfide		1/20 96-hr TL_m
Sulfate	250.	
Total dissolved solids	500.	
pH (ion conc., not mg/l)		6.5 – 8.3 swimming
Desirable range	6.0 – 8.5	6.0 – 9.0 other
Maximum range	5.5 – 9.0	5.0 – 9.0 other

[a]Source: U.S. Department of Health, Education and Welfare (1962), McKee and Wolf (1963), FWPCA (1968).

[b]For public, farmstead, and industrial food processing.

[c]All others not listed to be determined on individual bioassays.

1962; McKee and Wolf, 1963; FWPCA, 1968). At or below these levels, no harmful effects would be experienced. McKee and Wolf (1963) have pointed out that in some instances there were no adverse effects experienced from ingestion of larger quantities, so the recommended levels serve primarily as guidelines. Data concerning long-term effects are needed also, according to these authors.

G. Sediments and Turbidity

1. Source of sediment loads

Stream sediments are primarily soil and mineral particles carried from the land by the washing action of intense rainfall and floodwaters. Several reports have indicated that sediment is not only a major pollutant of the nation's streams, but is the largest single pollutant of the nation's streams (Water Resources Policy Commission, 1950; Browning, 1967). Natural land erosion has been aggravated by improper land use, through poor agricultural, mining, and urban land use and development practices. The suspended solids loadings which reach the streams from direct surface runoff have been estimated to be at least 700 times the loadings originating from sewage discharges (U.S. Senate Select Committee, 1960e). Although reductions of 50 to 75% in sediment production appears economically possible in most agricultural watersheds, this would require substantial expenditures and many years of effort.

The physical and economic damage caused by excessive sediment discharge and siltation are (U.S. Senate Select Committee, 1960e):

1. Adverse effects upon the plant and aquatic environment.

2. Additional damage during floods due to sediment.

3. Reduction of reservoir storage capacity.

4. Increased cost of treating turbid waters for beneficial use.

5. Miscellaneous adverse effects upon irrigation, navigation, and hydroelectric facilities.

Countereffects of removing turbidity from surface waters were discussed by Baxter (1966) who noted that the revived algal environment required new treatment methods and attendant costs for taste and odor control. Evaluation of the relationship of natural sediment loads to discharge made for the Ohio River (Hoak and Bramer, 1956) yielded a quantitative relationship permitting comparisons to be made between natural and industrial pollution. It was suggested that regulations governing discharge of suspended inorganic solids should be related to the normal load of such material carried by the receiving stream. Suspended organic solids in an active aquatic environment will include the plankton in addition to materials discharged as wastes (McKee and Wolf, 1963).

Determination of suspended sediment loads has been important in studies of the erosion process and in evaluating the problems of siltation. Both the weight and volume of sediment are important measures of these effects (Linsley et al., 1949, 1958). Turbidity has been explained as the measure of the extent to which the intensity of light passing through the water is reduced by suspended material (and colloidal), and has represented only one effect of suspended solids in general (Sawyer, 1960; McKee and Wolf, 1963; Standard Methods, 1965). Limits placed upon turbidity also limit the level of suspended solids, although a direct relationship is not evident. In sanitary engineering, turbidity has been measured in standard units, called Jackson Turbidity Units or JTU, and is determined by the depth of water at which a candle flame can be distinguished clearly. In the aquatic environment, the Secchi disk has been used extensively to measure water turbidity, with the turbidity related to the depth at which white portions of the disk are no longer distinguishable from the black portions.

Turbidity is controlled closely in water supplies where clarity is used as an indicator of an adequately treated water. The effects upon the aquatic environment were stated as being fourfold (McKee and Wolf, 1963):

> 1. By interfering with the penetration of light, it militates against photosynthesis and thereby decreases the primary productivity upon which the fish-food organisms depend, diminishing fish production as a consequence.
>
> 2. At very high concentrations, the particulate matter that produces turbidity can be directly lethal.
>
> 3. By excluding light, turbidity makes it difficult for fish to find food, but conversely smaller fish may be similarly protected from predators.
>
> 4. Turbidity modifies the temperature structure of impoundments, lowering the bottom temperatures and thus the productivity.

Field observations and laboratory bioassays have shown that fish can stand high amounts of turbidity for short periods, enabling them to survive during flood periods or other extreme conditions of short duration. The summary of McKee and Wolf (1963) indicated that most warm water species will survive 7 to 17 days at turbidities up to 100,000 to 200,000 ppm.

2. Turbidity, sediment limits, and criteria

According to standards accepted in the United States, the turbidity of a drinking water following complete treatment should be no greater than 5 JTU (U.S. Department of Health, Education and Welfare, 1962). Many treated surface waters have turbidities below 1 JTU. The American Water Works Association (AWWA) has recently adopted a treated water turbidity goal of 0.1 JTU. The compilation by McKee and Wolf (1963) showed that the type and characteristics of the colloidal and suspended material will have as much influence upon treatment effectiveness as will the amount of solids. The recent recommendation of the Committee on Water Quality Criteria (FWPCA, 1968) stated that any increase in turbidity, and fluctuations thereof, should be considered to be in excess of permissible variation if the increase caused additional treatment costs.

For the aquatic environment, it was recommended that turbidity due to a waste discharge should not be greater than 50 JTU in warm water streams and 10 JTU in cold waters. Suspended solids were limited also in several industrial processes not related to water consumption or in food production where drinking water standards apply.

H. Radioactive Substances

Radioactivity was considered to be the foremost of the extraneous substances found in water (McKee and Wolf, 1963). Radioactivity at abnormal levels was noted to be detrimental to several uses of water, especially to human health. As with the toxic substances discussed previously, they may be consumed directly in water or may be ingested through consumption of food products in which radioactivity has been accumulated.

Summary reports have indicated that few natural sources of radioactivity exist, and of more concern today are the activities of man in the atomic energy industry, its mining processes, and in the detonation of nuclear devices with attendant fallout. Radioactivity is considered to be an indestructable property, with natural decay as the inherent mechanism for its decreasing effect with time and subsequent return to a stable state. Three major factors control the importance of any specific radioactive waste (U.S. Senate Select Committee, 1960e): (1) the quantity of material involved, (2) the duration of the waste discharge, and (3) the degree of hazard associated with each specific radioisotope.

Radiation from radioactive substances has been divided into four general categories by McKee and Wolf (1963): (1) alpha particles, (2) beta particles, (3) gamma rays, and (4) neutron particles. All have been encountered in radioactive waste disposal. The first two are hazardous in water and food because they can become concentrated in specific tissues when ingested by humans. External exposure to any of the latter three types can be dangerous because of their power to penetrate the skin and flesh. The biological effects of radiation were classified as (1) somatic, or directly affecting the individual cells and organisms, and (2) genetic, affecting the descendents of the individual but with no influence upon the irradiated individual.

Three methods are used to reduce radioactive substances to tolerable limits: (1) dilution with water, (2) dilution with stable isotopes, or (3) concentration and lengthy storage to permit disintegration to acceptable levels. The most satisfactory method will depend on the hazard involved with a specific substance. Problems may be encountered in land disposal, ocean burial, and in nuclear industrial accidents (U.S. Senate Select Committee, 1960e). Wastes from nuclear operations having a high level of radioactivity are monitored and controlled by the Atomic Energy Commission. However, a problem of considerable magnitude exists in the area of low-level radioactive wastes which originate in myriads of small operations and subsequently reach natural waters following discharge to municipal sewer systems (McKee and Wolf, 1963). These sources include medical and dental clinics, and many small industrial operations.

The three radioactive characteristics or constituents which have been listed in water supply surface water criteria (U.S. Department of Health, Education and Welfare, 1962; FWPCA, 1968) are

1. Gross beta emission
   1,000 pc/l or less, preferably less than 100
2. Radium-226
   3 pc/l or less, preferably less than 1
3. Strontium-90
   10 pc/l or less, preferably less than 2

These limits have also been recommended as satisfactory for aquatic life (FWPCA, 1968).

I. Heat as a Pollutant

1. Heat and related temperature aspects

Heat was not specifically mentioned as a pollutant by the Water Resources Policy Commission (1950) in an extensive report of the nation's water problems. However, it was included in four different reports by the U.S. Senate Select Committee (1959a, 1960a, 1960e, 1960h) a decade later. These documents indicated that over 94% of the water used for industrial purposes was used for cooling. Steam-electric power plants, steel mills, petroleum refineries, and various other industrial and chemical plants are the largest users. The used water, containing substantial increased amounts of heat, is frequently discharged directly to surface water bodies.

The effect of heat has been summarized in several reports (U.S. Senate Select Committee, 1960e; McKee and Wolf, 1963; Tarzwell, 1966; Committee on Thermal Pollution, A.S.C.E., 1967). Heat as a pollutant reduces the ability of water to hold oxygen in solution. Thus, in reducing the saturation value of dissolved oxygen and in increasing the rate of biological metabolism it has the net effect of increasing the effects of organic pollution on a surface water. There is also a direct detrimental effect upon fish and other aquatic life as the temperature environment is changed. Only small increases in temperature can be tolerated by most species of fish, and substantial increases can result in complete change or even elimination of the existing aquatic life. Fish kills are a persistent problem associated with thermal pollution. Not only has industry aggravated the problem, but excessive summer temperatures in most of the United States have contributed to natural thermal pollution.

Temperature effects upon aquatic life have been summarized by Tarzwell (1966). For aquatic fauna, water temperatures and dissolved oxygen values are interrelated, and temperature largely governs biological activity and oxygen consumption. For trout and other cold water species, temperatures above 70 deg F are undesirable and should be experienced only a few hours a day. For well-rounded warm water game fish populations, temperatures should not exceed 93 deg F, and only on the afternoons of the hottest days should water temperatures be permitted to exceed the range of 90 to 93 deg F in the central regions of the United States. Maximum temperatures of unpolluted waters have naturally exceeded these limits during the summer season, with maximum daily water temperatures of over 95 deg F being recorded during the period 1952-1962 (Harmeson and Schnepper, 1965). The complete range of temperature variation in the United States, both temporally and spatially, was reported to be from 32 deg F to over 100 deg F (FWPCA, 1968).

A narrow temperature range exists for optimum rates of growth and reproduction of fish (Tarzwell, 1966). McKee and Wolf (1963) summarized from several sources the optimum values or ranges, as shown in Table 7. Adverse effects due to sudden changes of temperature were also noted, as were effects upon lower forms of aquatic and marine life. The optimum temperature range for diatoms was listed as 15 to 25 deg C, for green algae, 25 to 35 deg C, and for blue-green algae, 30 to 40 deg C.

Amelioration of thermal effects was discussed in the report of the U.S. Senate Select Committee (1960e). The remedy for natural heat

Table 7. Preferred or optimum temperature range[a] for selected fish species

Common name of fish	Optimum or preferred temperature range Deg C	Deg F
Rainbow trout	13	55
Chum salmon	13.5	56
Sockeye salmon	15	59
Lake trout	15-17	59-63
Coho salmon	20	68
Greenthroat darter	20-23	68-73
Largemouth bass	22-25	72-77
Roach	23-24	73-75
Guppy	23-25	73-77
Carp	32	89-90

[a]Source: Summarized from McKee and Wolf (1963).

effects is limited to reservoir storage to permit cooler water to be available for release. Recirculation, cooling ponds, spraying ponds, conventional cooling towers and air cooling methods are means of reducing the amount of cooling water required for industrial use. Careful planning was recommended in the location of plants requiring cooling water and in discharging the used heated water to surface streams and lakes. Use of the various methods that are recommended today would avoid depletion of the pollution assimilating capacity of surface waters and permit the aquatic environment to be acceptable for recreation, fish and wildlife uses.

2. Temperature limits and criteria

The recent Committee on Water Quality Criteria noted that fixed criteria for water temperature could not be expressed specifically because geographic conditions vary so widely. Six conditions to be avoided were listed for minimizing the adverse effect of high temperatures on a water supply.

1. Water temperatures higher than 85 deg F;

2. More than 5 deg F water temperature increase in excess of that caused by ambient conditions;

3. More than 1 deg F hourly temperature variation over that caused by ambient conditions;

4. Any water temperature change which adversely affects the biota, taste, and odor, or the chemistry of the water;

5. Any water temperature variation or change which adversely affects water treatment plant operation;

6. Any water temperature change that decreases the acceptance of the water for cooling and drinking purposes.

Industry in general has accepted surface waters at its natural temperature levels, and temperatures up to 100 deg F have been used in certain operations (FWPCA, 1968).

Recommendations for temperature criteria for the aquatic environment have also been made (FWPCA, 1968):

I. Recommendation for Warm Waters: To maintain a well-rounded population of warm-water fishes, the following restrictions on temperature extremes and temperature increases are recommended:

1. During any month of the year, heat should not be added to a stream in excess of the amount that will raise the temperature of the water (at the expected minimum daily flow for that month) more than 5 deg F. .... the increase should be based on the monthly average of the maximum daily temperature.

2. The normal daily and seasonal temperature variations that were present before the addition of heat, due to other than natural causes, should be maintained.

3. The recommended maximum temperatures that are not to be exceeded for various species of warm water fish are given in ... III.

II. Recommendation for Cold Waters: Because of the large number of trout and salmon waters which have been destroyed, or made marginal or nonproductive, the remaining trout and salmon waters must be protected if this resource is to be preserved:

1. Inland trout streams, headwaters of salmon streams, trout and salmon lakes and reservoirs, and the hypolimnion of lakes and reservoirs containing salmonids should not be warmed. No heated effluents should be discharged in the vicinity of spawning areas.

(For other types and reaches of cold-water streams, reservoirs, and lakes, the restrictions in I were to apply)

III. Provisional maximum temperatures recommended as compatible with the well being of various species of fish and their associated biota:

93 deg F: Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, and gizzard shad.

90 deg F: Growth of largemouth bass, drum, bluegill, and crappie.

84 deg F: Growth of pike, perch, walleye, smallmouth bass, and sauger.

80 deg F: Spawning and egg development of catfish, buffalo, threadfin shad, and gizzard shad.

75 deg F: Spawning and egg development of largemouth bass, white, yellow, and spotted bass.

68 deg F: Growth or migration routes of salmonids and for egg development of perch and smallmouth bass.

55 deg F: Spawning and egg development of salmon and other than lake trout.

48 deg F: Spawning and egg development of lake trout, walleye, northern pike, sauger, and Atlantic salmon.

IV. APPLICATION OF WATER QUALITY STANDARDS

A. General

The ability to identify and measure the effects of potential pollutants has led to the formal adoption of water quality standards and related criteria. Many of the individual states, interstate, and regional agencies have adopted laws and regulations which provide for criteria, standards, and/or treatment requirements. Summaries of these were presented by McKee and Wolf (1963). Additional progress made since the promulgation of federal requirements for standards was reported by Agee and Hirsch (1967). The principles which underlie the establishment of effluent and stream standards for water pollution control were stated by Gabrielson (1965):

> Effective pollution control depends largely on the acquisition of new knowledge and new techniques that lead to the development of an improved level of water resources management in order to restore, maintain, and improve water quality. The objective is to make it possible, and mandatory, for each water user to return his process or wastewater to the source in a condition suitable for municipal, industrial, agricultural, recreational, and all other uses that may be made of water from that common source.
>
> To reach this stage of compatible water use, the quality of water necessary for each of the uses that is intended must be known. The minimum quality at any point in a water source must be based on the most critical requirements of all the uses to which that water may be put including fish, wildlife, and recreation.
>
> This means that the quality of water that is needed for every water use will have to be determined. Until all these quality requirements are known, it will continue to be difficult, if not virtually impossible, to detect and to designate other than gross or obvious pollution, to measure its undesirability, and to evaluate and recommend control measures.

Gabrielson further contended that water quality criteria give purpose to efforts directed towards improving stream water quality. These criteria were the means of providing reason and interpretation to the undefinable philosophy of "keeping waters as clean as possible," a philosophy criticized by Wendell (1966). Only if based on thorough research information could quality criteria substitute fact for supposition. Incorporation of criteria into stream or effluent standards provides all water users with specific goals for restoring or enhancing the water quality in a stream. Different treatment methods can then be evaluated for maintaining the desired water quality in a stream. Formal adoption of criteria (as stream standards) assists in the abatement of pollution by providing a firm basis for legal enforcement.

Because water quality criteria apply to definite uses of water, identification must be made of the uses which are to be protected (Hubbard, 1965; Lyon, 1965). Standards of quality may then be fixed for each respective use. Some agencies have established general statewide guides or standards of quality applicable to all waters of the state (McKee and Wolf, 1963). In others, stream standards for specific streams have been adopted which apply to the quality of the receiving waters after discharge and dilution of the waste effluents. Some state and interstate agencies have preferred use of effluent standards, and in some a combination of these several techniques have been employed. Paramount in the development and application of standards has been a problem of classifying streams according to beneficial use, and then establishing standards of quality for protecting the respective uses.

The U.S. Public Health Service (1958) suggested that classifying surface waters according to their present and future best uses should be authorized to facilitate development of a comprehensive pollution control program. Standards of water quality might then be adopted which would be consistent with the best present and future uses of such waters. Obtaining the desired flexibility in the statutes for making changes to improve further the water quality in a stream was reported to be a major obstacle in adoption of stream classification methods (McKee and Wolf, 1963; Hubbard, 1965; Lyon, 1965).

B. Stream Classification Methods

1. <u>Early techniques</u>

One of the earliest uses of stream classification was in Pennsylvania in the 1930's (McKee and Wolf, 1963; Lyon, 1965). Following the completion of general studies of the major streams of the state by the Division of Sanitary Engineering, the Sanitary Water Board established a stream classification system as an adjunct to the establishment of equitable treatment requirements (effluent standards). The four stream classes were: (1) those streams into which all wastes that were discharged were to receive complete treatment of its equivalent (85% BOD removal), (2) those streams for which all wastes were to be given primary treatment (settling, grease removal, chlorination), (3) acid-impregnated streams (acid-mine drainage), that for the present would require no treatment of wastes received therein, and (4) those streams for which a degree of waste treatment somewhere between primary and complete would be required, as applicable to particulate rivers or reaches of the rivers. The degree of treatment was to be specified in each individual case for the fourth category.

A similar system was adopted by the Ohio River Valley Water Sanitation Commission (ORSANCO) in 1949 (McKee and Wolf, 1963; Cleary, 1967). The 981-mile Ohio River was divided (by 1954) into seven zones, with a specific set of requirements for each. Variations of streamflow, quantities of sewage discharged, proximity of downstream water supply intakes to waste discharge points, and the natural assimilative capacities of the river along its length were evaluated in selecting the reach of river to be assigned a particular zone. Sewage treatment standards were established for each zone. This was considered to be a major accomplishment, as less than 1% of the population living along the river were served by sewage treatment facilities prior to 1949.

2. Modern classification methods

A refinement of the initial classification concept to identify more clearly the beneficial uses being protected or enhanced followed these early efforts. The classification system adopted in New York State for surface, tidal, and groundwaters is typical of those existing in many of the heavily industrialized eastern seaboard states. Seven classes and associated standards for fresh surface waters were formulated (McKee and Wolf, 1963; New York Temporary State Commission, 1965):

1. Class AA. Best usage: Source of water supply for drinking, culinary or food processing purposes and any other usages. Related conditions: The waters, if subjected to approved disinfection treatment, with additional treatment if necessary to remove naturally present impurities, will meet U.S. Public Health Service drinking water

standards, and are or will be considered safe and satisfactory for drinking water purposes.

2. Class A. Best usage: Source of water supply for drinking, culinary, or food processing purposes, and any other usages. Related conditions: The waters, if subjected to approved treatment equal to coagulation, sedimentation, filtration, and disinfection, with additional treatment to reduce naturally present impurities, meet or will meet U.S.P.H.S. drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.

3. Class B. Best usage: Bathing and any other usages except as a source of water supply for drinking, culinary, or food processing purposes.

4. Class C. Best usage: Fishing and any other usages except for bathing or as a source of water supply for drinking, culinary, or food processing purposes.

5. Class D. Best usage: Agriculture or source of industrial cooling or process water supply and any other usage except for fishing, bathing, or as a source of water supply for drinking, culinary, or food processing purposes. Related conditions: The waters will be suitable for fish survival; the waters without treatment and, except for natural impurities which may be present, will be satisfactory for agricultural usages or for industrial process and cooling water; and with special treatment as may be needed under each particular circumstance will be satisfactory for other industrial processes.

6. Class E. Best usage: Sewage or industrial wastes or wastes disposal and transportation or any other usages except agricultural, source of industrial cooling or process water supply, fishing, bathing, or source of water supply for drinking, culinary, or food processing purposes.

7. Class F. Best usage: Sewage or industrial wastes or other wastes disposal.

Three classes for tidal salt waters and two for groundwater were included in the New York State classification, providing a total of 12 classifications:

8. Class SA. Best usage: Shellfishing for market purposes and any other usages.

9. Class SB. Best usage: Bathing and any other usages except shellfishing for market purposes.

10. Class SC. Best usage: Fishing and any other usages except bathing or shellfishing for market purposes.

11. Class GA. Best usage: Source of water supply for drinking, culinary or food processing purposes and any other usages.

12. Class GB. Best usage: Source of industrial or other water supply and any other usages except as source of water supply for drinking, culinary or food processing purposes.

In addition, three special classes were assigned to international boundary waters or other interstate boundary waters.

Seven general categories of potential pollutants were introduced to provide criteria for measuring water quality:

1. Floating and settleable solids, and sludge deposits;

2. Sewage or waste effluents;

3. Odor producing substances contained in wastes;

4. Phenolic compounds;

5. pH;

6. Dissolved oxygen;

7. Toxic wastes, oil, deleterious substances, color and/or other wastes or heated liquids.

Standards of quality were then established and adopted. Two conditions which applied to all classifications and standards were:

1. In any case where the waters into which sewage, industrial wastes or other wastes effluents discharge are assigned a different classification than the waters into which such receiving waters flow, the standards applicable to the waters which receive such sewage or wastes effluents shall be supplemented by the following: "The quality of any waters receiving sewage, industrial wastes or other wastes discharges shall be such that no impairment of the best usage of waters in any other class

> shall occur by reason of such sewage, industrial wastes or other discharges."
>
> 2. Natural waters may on occasion have characteristics outside of the limits established by the standards. The standards adopted relate to the condition of waters as affected by the discharge of sewage, industrial wastes or other wastes.

A careful approach was outlined for classifying surface waters in North Carolina, as provided in the water pollution statute (Hubbard, 1965). The enabling act, passed in 1951, provided authority for the State Stream Sanitation Committee to:

> 1. Develop and adopt, after proper study, a series of classifications, and the standards applicable to each such classification, which will be appropriate for the purposes of classifying each of the waters of the state in such a way as to promote the policy and purposes of the statute most effectively.
>
> 2. Survey all the waters of the state and separately identify those which in the opinion of the committee ought to be classified separately.
>
> 3. Assign to each identified water of the state such classification, from the series as adopted and specified previously, as the committee deems proper in order to promote the policy and purposes of the statute most effectively.

Guidelines were included in the North Carolina statute for establishing criteria which would be used in developing classifications, standards, and assignment of classifications. These included identification of hydrologic characteristics of each stream; economics and physical characteristics of the district bordering upon the surface waters; past, present, and future beneficial uses of water; extent to which present waters are receiving wastes; and relative economic values which must be considered in improving or attempting to improve such waters.

The North Carolina classification system followed closely that of New York State:

1.	Class A-I	Same as Class AA of New York State
2.	Class A-II	Same as Class A of New York State
3.	Class B	Same as Class B of New York State
4.	Class C	Same as Class C of New York State
5.	Class D	Same as Class D of New York State
6.	Class E	Same as Class E of New York State with following exception: Waters will be suitable for navigation where navigable waters are involved, and may be used for waste disposal to the extent that the stream will accommodate same within the limits of the prescribed specifications for this class. This class will not be assigned to waters which can, in the light of considerations prescribed by the statutes, be properly assigned to a higher class.

There was no lower class than Class E.

The Pollution Control Council, Pacific Northwest Area (1961) adopted water quality objectives and minimum treatment requirements in 1952. The area of applicability included the Columbia River basin in the states of Montana, Wyoming, Idaho, Utah, Nevada, Washington, and Oregon, and the coastal drainage areas in Oregon, Washington, the Province of British Columbia in Canada, and southeastern Alaska. The objectives were applicable to receiving waters, both fresh and salt, and for underground waters. Recognized beneficial uses included in the classification system were:

1. Class A. Water supply, drinking, culinary and food processing: without treatment other than simple disinfection and removal of naturally present impurities.

2. Class B. Water supply, drinking, culinary and food processing: with treatment equal to coagulation, sedimentation, filtration, disinfection and any additional treatment necessary for removing naturally present impurities.

3. Class C. Bathing, swimming and recreation.

4. Class D. Growth and propagation of fish, shellfish, and other aquatic life.

5. Class E. Agricultural and industrial water supply: without treatment except for the removal of natural impurities to meet special quality requirements.

The interior and less populated states frequently have selected fewer classes of beneficial water use (McKee and Wolf, 1963). In the Miami River basin, an intrastate stream in Ohio, the policy adopted was to fix water quality objectives that were consistent with recognized water uses: (1) domestic water supply, (2) industrial water supply, (3) fish and wildlife, and (4) limited recreation. Streams and sections of streams were divided into zones of water quality according to the stated objectives, with municipal water supply having highest priority (McKee and Wolf, 1963; Cleary, 1967).

The States of Maine, New Hampshire and Vermont used four classes (Class A, B, C, and D) similar to the New York statute and classification system, but with Class D being assigned also to streams considered as primarily devoted to the transportation of sewage and industrial wastes without causing a public nuisance. South Dakota, as of 1960, had elected to use only two classifications. Class A waters were those surface waters, or parts thereof, in which the pollution and corruption entering such waters could be so controlled that the waters receiving such wastes would not be unwholesome or unfit for domestic use, or unsafe as a source of public water supply, or deleterious to fish or plant life, or cause a public nuisance. Class B waters were those waters, or parts thereof, which were designated to be of more importance to the welfare of the people of the state as carriers of waste, providing such wastes were not detrimental to the public health.

Gabrielson (1965), however, deplored the use of stream classification in the sense that it might involve the assignment of waste-carrying capacities, such as the low priority classes of several of the states. He believed that states should be guided toward the objective of assuring that the "quality of the overall water resource for all uses is not destroyed or impaired." The guidelines issued by the U.S. Department of Interior (1966) to assist the states in establishing water quality standards supported this view, specifically in stating (Guideline 2), "No stream can be used for the sole purpose of transporting wastes."

Introduction of the newer concept of improving and enhancing the quality of the water resource, including surface waters, for all uses may lead to a decrease in the number of classes and specific beneficial uses recognized in a classification system. Water quality suitable for the quality users of higher priority will obviously satisfy those of lower priority, such as navigation and waste disposal. As an example, the Ohio River Valley Water Sanitation Commission (1966) adopted stream water quality criteria and minimum conditions as a coordinating step with the member states in meeting the requirements of the federal Water Quality Act of 1965. The adopted criteria were not to be regarded as standards universally applicable to all streams, but certain minimum conditions were to form part of the ORSANCO standards and would be applicable to all streams at all places at all times and for all uses. Standards for specific waters would be promulgated following investigation, due notice and hearing. The beneficial uses of water for which stream water quality criteria were adopted included

1. Public water supplies
2. Industrial water supplies
3. Aquatic life
4. Recreation, including a water contact sports category (primary and secondary contact recreation).

Other beneficial water users making use of the surface water resource would be required to observe the designated levels of protection as applied to the point of use, and further degradation of the water quality would not be permitted.

C. Effluent Standards, or Minimum Treatment Standards

Control over the discharge of wastes into streams and watercourses has had two objectives: (1) the elimination of "obvious" pollution, or the nuisance category, and (2) providing an initial concept of equity in regulation efforts as water pollution control programs were initiated (Lyon, 1965). Early state statutes, similar to that written in Iowa (Schliekelman, 1967) which made it unlawful to discard certain undesirable residues into streams is a historical example of an effluent standard having uniform applicability to all residents.

The State of Pennsylvania, in adopting its original classification system, applied "equitable" treatment requirements for each of four classes of streams (Lyon, 1965). Complete treatment, primary treatment with chlorination, intermediate levels of treatment, and no treatment in certain acid-impregnated streams were the categories listed.

The initial ORSANCO classification of the Ohio River into seven zones resulted in the assignment of effluent standards for sewage treatment plants. These standards (McKee and Wolf, 1963; Cleary, 1967) included control of the following pollutants: settleable solids, total suspended solids, BOD, and coliform bacteria. Values assigned to the seven zones are listed in Table 8.

A basic industrial waste requirement for providing control of chloride discharges was adopted by ORSANCO in 1960 (Cleary, 1967). Discharges subject to compliance were called "significant loads" and were identified as:

1. Any existing discharge to the Ohio River or its tributaries which is equal to or greater than 25 tons per day.

2. Any discharge from new or expanded operations to the Ohio River or its tributaries which is equal or greater than 5 tons per day.

3. Any discharge less than any of the above values if it causes local degradation of water quality.

The State of Louisiana gave special attention to the discharge of sugar mill wastes, as reported by questionnaire (McKee and Wolf, 1963). Included in the regulations were control over acid and alkali wastes, completion of waste stabilization prior to discharge, requiring all cane wash water to be settled and then impounded for at least 30 days, and limiting condenser water discharges. The State of Missouri included both general objectives and specific objectives in its regulations. All wastes, including sanitary sewage, storm water, and industrial

Table 8. Effluent standards for the Ohio River[a]

Zone	Reach	Treatment requirement for indicated pollutant, percent removal or reduction: Settleable solids	Total suspended solids	Biochemical oxygen demand	Coliform organisms
1.	Pittsburgh and vicinity	Substantially complete removal	45	50	80, May-Oct. 85, Nov.-Apr.
2.	Pittsburgh to Huntington	Substantially complete removal	45	50	80, May-Oct. 85, Nov.-Apr.
3.	Huntington to Cincinnati	Substantially complete removal	45	—	90, May-Oct. 80, Nov.-Apr.
4.	Cincinnati Pool	Substantially complete removal	45	65[b]	—
5.	Cincinnati Pool to Owensboro	Substantially complete removal	45	—	—
6.	Owensboro to Henderson	Substantially complete removal	45	—	85, May-Oct. 65, Nov.-Apr.
7.	Henderson to Cairo	Substantially complete removal	45	—	—

[a]Source: Cleary (1967).

[b]Reduction of only 35% permitted if 4 mg/l dissolved oxygen are maintained in the river.

effluents, were to be in such condition when discharged that they would not create conditions adversely affecting the use of those waters for domestic water supply, industrial water supply, navigation, fish and wildlife, recreation, agriculture or other riparian activities. Adverse conditions were defined as:

1. Excessive bacterial, physical, or chemical contamination.

2. Unnatural deposits in the stream, interfering with fish and wildlife, recreation, or destruction of esthetic values.

3. Materials imparting objectionable colors, tastes, or odors to waters used for domestic or industrial water supply.

4. Floating materials, including oils, grease, garbage, sewage solids, or other refuse.

Specific requirements to meet these general objectives were:

1. Substantially complete removal of floating and settleable solids, oil, etc.

2. Removal of not less than 45 percent of total suspended solids.

3. Eliminate or reduce highly toxic wastes to safe limits.

Other requirements were based upon criteria and objectives established for specific streams.

In Oregon, the adopted rules outlined the minimum degree of treatment necessary for discharge of waste effluents into surface waters. As specified for surface waters of various classes, the criteria were:

1. Class A waters. The waste effluents are to be so treated that they (a) are free of noticeable floating solids, oil, grease, sleek, and practically free of suspended solids, and (b) indicate an average reduction in BOD of not less than 85 percent, and at no time have a BOD in excess of 50 mg/l.

2. Class B waters. The waste effluents are to be treated sufficiently to (a) be free of noticeable floating solids, oil, grease and sleek, (b) indicate an average suspended solids reduction of at least 55 percent, and (c) indicate an average reduction in BOD of not less than 35 percent, and at no time have a BOD in excess of 125 mg/l.

3. Class C waters. Only temporary permits will be issued for discharge of municipal and sanitary wastes without treatment.

Effluent standards adopted in 1959 in Colorado provided that the residue content of effluents was not to exceed:

1. 0.5 ml/l settleable organic matter.

2. 75 mg/l suspended organic matter.

3. 50 mg/l BOD for combined suspended and dissolved organic matter.

4. 1,000 per ml coliform count as an average, based upon not less than four samples taken at the rate of at least one sample a day over a period of four consecutive days.

The State of Connecticut reported that effluent standards had been assigned to two river basins, the Quinnipiac and Hockanum River valleys. In both, all sanitary wastes, before being discharged to the rivers or their tributaries, were to receive a degree of treatment equal to that ordinarily expected from a well-designed and well-operated plant including high-rate trickling filters and chlorination. Industrial wastes were assigned special limits. Specific effluent criteria assigned were:

1. Range of pH permitted, 6.5 to 8.5.

2. Suspended solids, not to exceed 30 mg/l.

3. Residual BOD, not to exceed 25 mg/l in the Quinnipiac, 30 mg/l in the Hockanum.

4. Color and turbidity, not to exceed 50 mg/l in the Quinnipiac, and not to be increased more than 5 mg/l above existing levels in the Hockanum.

5. Dissolved metals, and oils and greases, 5 mg/l each and 20 mg/l for the latter category, for the Quinnipiac.

At the time of the report of McKee and Wolf (1963), these were the only states which reported specific effluent standards. However, through the issuance of permits for the construction of sewers, outfalls, and treatment works, most if not all of the states had a real measure of control over the discharge of waste effluents on a case by case basis (Clarenbach, 1967; Cleary, 1967). Cleary reported on the effectiveness of this means of control in improving water quality in the Ohio River basin (1967, p. 122-124). In conjunction with water quality standards for streams, Lyon (1965) indicated that effluent standards would again be revitalized, and closer control over effluents would be necessary to achieve optimum economic results in water quality management. A blanket requirement for the equivalent of secondary treatment of all wastes appears evident in recent discussions by the FWPCA. Agee and Hirsch (1967) stated that Guideline 8 (U.S. Department of Interior, 1966),

> No wastes are to be discharged without treatment or control if such wastes are amenable to treatment, and shall receive the best practicable treatment normally

was interpreted as requiring secondary waste treatment by municipalities and a correspondingly high degree of waste treatment and control by industries. This interpretation is currently being criticized by some states as being "treatment for treatments sake." Tertiary treatment for municipal wastes was also mentioned as a distinct possibility.

D. Basic Considerations in Establishing Water Quality Standards for Streams

1. ORSANCO's four freedoms

The Ohio River Valley Water Sanitation Commission (ORSANCO) in 1955 established basic or minimum conditions to be maintained in receiving waters, but these were specifically applicable to discharge of industrial waste effluents (Cleary, 1967). Minimum conditions were adopted in 1966 as criteria applicable to all streams at all places and at all times (ORSANCO, 1966), and for all states in the Ohio River basin. The minimum conditions specified that surface waters were to be:

1. Free from substances attributable to municipal, industrial, or other discharges that will settle to form putrescent or otherwise objectionable sludge deposits.

2. Free from floating debris, oil, scum and other floating materials, attributable to municipal, industrial or other discharges in amounts sufficient to be unsightly or deleterious.

3. Free from materials attributable to municipal, industrial, or other discharges producing color, odor or other conditions in such degree as to create a nuisance.

4. Free from substances attributable to municipal, industrial or other discharges in concentrations or combinations which are toxic or harmful to human, animal or aquatic life.

ORSANCO referred to this group as the "four freedoms" (Cleary, 1967). These minimum conditions for stream water quality are similar to the conditions to be achieved by certain effluent standards outlined in the previous section. According to Cleary, these minimum conditions permit the elimination or prevention of nuisance conditions, esthetically offensive conditions, and the practical considerations of the dangers of toxic compounds.

These minimum conditions have been recommended as descriptive criteria by the Committee on Water Quality Criteria (FWPCA, 1968), for esthetic purposes which "add to the quality of human experience" and which are intended to cover degradation from discharges or wastes. The term "free" was acknowledged to be a practical impossibility, with the presence of some pollutants being inevitable. Reasonable interpretation of the term was intended in practical application and proposed enforcement actions.

2. Additional factors and problems

Assignment of specific water quality criteria for each beneficial use or class of stream has been and will be accomplished by selecting the potential pollutants and assigning the numerical values which are to govern. McKee and Wolf (1963) summarized those received on a questionnaire basis from the states and interstate agencies, as of 1961. Additional criteria developed through research efforts were summarized in a previous section. Bioassays, hydrologic studies, and physical and economic aspects need to be considered in adoption of specific criteria for a particular stream, or for a class of stream in a statewide stream classification system.

a. Stream sampling concepts In regard to frequency of sampling, Streeter (1949) considered as noteworthy those criteria which selected a 30-day period (1 month) as the time unit in fixing limiting requirements for such parameters as coliform bacteria, dissolved oxygen and biochemical oxygen demand. He advocated the separation of these requirements according to monthly averages, and permissible daily maxima or minima. Selection of the monthly time period afforded an equitable basis of indicating sanitary conditions in a river during critical times of the year with respect to natural hydrologic variability and to various stream uses which might be seasonal. The additional specification of daily maximum or minimum values provides the required protection to aquatic and other uses which must be safeguarded from critical periods of as short as a few hours. Studies of the Ohio River indicated that there was a close relationship between desirable minimum values and monthly averages which would permit selecting reasonable values for each.

McKee and Wolf (1963) also noted the variability of concentrations of specific substances in natural water, and the need to define each analysis in terms of frequency of sampling, including a measure of central tendency (such as the arithmetic mean) and an indication of the deviation from the mean (standard deviation). In practice, however, the 80% or, at the opposite end of the spectrum of measured values, the 20% values have commonly been used to indicate variability, as have the 95% confidence limits. In case of infrequent sampling, it was recommended that the additional requirement be superimposed that no three consecutive samples can exceed the designated concentration. Cleary (1967) illustrated the use of "qualigrams" in presenting probability data for various pollutants as obtained and analyzed for the Ohio River.

b. Hydrologic factors The variability of streamflow introduces a probability factor to the possibility of having insufficient streamflow for dilution and assimilation of waste effluents. McKee and Wolf

(1963) discussed the need for acquiring data on minimum flows and their duration and determining the probability of occurrence of low flows. The duration curve was used in several water quality control programs, with the selected rate of flow varying from the 1% flow (i.e., a discharge exceeded 99% of the time) to the 10% flow figure (exceeded 90% of the time), depending upon whether public water supplies or less critical water uses were involved. The duration curve (Linsley et al., 1949, 1958) is compiled from data for a long period of years to show the long-period distribution of flow (daily, weekly, or monthly) without regard to the chronological sequence of the flows. Percent of time values actually are averages and do not apply to any single year or lesser period. McKee and Wolf (1963) pointed out that duration curves may have advantages for specific applications, but they do not reveal the probability of occurrence of drought flows for extended periods.

Analysis of low-flow frequencies, including the magnitude of flow, length of low-flow period for consecutive days, and the frequency of such magnitudes and periods, must be made for complete identification of the low-flow characteristics of a stream. Schwob (1958) completed a study of these characteristics for Iowa streams, determining the magnitude and frequency of minimum flows at selected gaging stations for various periods of consecutive days: 1, 7, 30, 60, and 183 days. Similar studies have been completed in other states (Kansas Water Resources Board, 1960).

Of the states which reported having stream water quality standards and related criteria as of 1961, only Missouri indicated that a specific low-flow probability would apply (McKee and Wolf, 1963). The 10% low-flow duration was selected for the Blue River basin. There was no mention made in the reports of other states of any selection of applicable low-flow magnitude or frequency, or of a specified duration. Presumably such criteria as adopted applied to the lowest flow experienced in the stream during a particular monthly period during which samples were obtained. The recent report by the Committee on Water Quality Criteria (FWPCA, 1968) made no specific mention of low-flow probability, and the lowest flows experienced are presumed to apply with the criteria presented.

McKee and Wolf (1963), however, listed four factors to be considered in selecting a minimum stream flow on which to base the evaluation of water pollution in streams:

1. Beneficial use of the water.

2. Probability that the selected dilution will not be reached, and the duration of periods during which such dilution will not be attained.

3. The economic damage that will be done if dilution is insufficient.

4. The cost of increased treatment to meet stricter dilution requirements.

3. Summary

It is concluded that the selection of minimum stream flows is as important as the selection of other criteria, for limiting concentrations of potential pollutants. Both will have an impact on the establishment and enforcement of meaningful water quality standards. Economic implications also are evident in this discussion of technical considerations. Arbitrary selection of either category, limiting concentrations or minimum low flows, may unduly constrain the economic dimension in evaluating the worth of programs for improving the quality of surface waters.

A comprehensive program for improving water quality must provide for obtaining adequate knowledge of the stream environment. The response of the stream to waste inputs must be expressed in mathematical terms if forecasting for future conditions is to be accomplished. Economic evaluation can lead the way to more optimum solutions for regional water quality improvement and related pollution control programs. These aspects will be considered in the remainder of the first part of this study.

V. MATHEMATICAL MODELS FOR STREAM BEHAVIOR STUDIES

A. General

Success of water quality management programs will ultimately depend on the ability to forecast accurately the levels of water quality which will occur under a given set of conditions. Mathematical expression of the response of the stream environment is essential to the development of forecasting techniques. The goal of mathematical modeling is to simulate the observed response within a specified or desired degree of accuracy.

The reaction of the stream environment upon receiving raw wastes or effluents from water pollution control plants was noted previously to consist of dilution, sedimentation, reduction, oxidation, reaeration, and the effect of sunlight and solar energy upon chemical, physical, and biological activity (Babbitt and Baumann, 1958). The three major aspects of natural purification in streams considered to be of major importance (McKee and Wolf, 1963) are:

1. The rate and extent to which pollutants are stabilized, assimilated or removed.

2. The resultant effect of stabilization on other significant parameters of water quality.

3. Corollary reactions such as algal blooms caused through nutrient enrichment.

The fate of pollutants in the stream environment depends on the type of pollutant, whether nonconservative or conservative. All of these effects must be expressed in mathematical relationships if effective simulation models are to be developed.

The technical relationships involving chemical, physical, and biological effects will be considered in this section. Initial mixing, dilution, dispersion and transport concepts will be studied first. Biological oxidation of organic wastes will be the second topic discussed. The importance of stream reaeration and the oxygen resources will be the third subject. The fourth and concluding section will be a discussion and summary of the several mathematical models which have been developed for simulating the observed response of the stream to waste inputs.

B. Initial Mixing, Dispersion, and Time of Travel Relationships

1. Dilution and mixing

Dilution at outfalls is accomplished through the direct physical mixing of effluent and stream discharges. If it is assumed that the mixing takes place rapidly in both lateral and vertical directions and that no chemical changes take place at the time of mixing, the concentration of a potential pollutant may be expressed (Babbitt and Baumann, 1958) as

$$C_m = \frac{C_e Q_e + C_r Q_r}{Q_e + Q_r} \qquad (1)$$

where

C_m = the amount or concentration of the substance in the mixture,

C_e = the concentration of the substance in the effluent,

C_r = the concentration of the substance in the receiving water,

Q_e = the quantity or rate of flow of the effluent, and

Q_r = the quantity or rate of flow of the receiving water.

McKee and Wolf (1963) elaborated on additional physical concepts and the time element as related to mixing. Three types of mixing were noted: lateral, vertical, and longitudinal mixing. Lateral mixing controls the rate at which the discharged effluent diffuses or moves across the stream, bank to bank. Vertical mixing regulates the extent that vertical stratification takes place, with increased mixing permitting material flowing in the lower water to move upward to the surface, etc. Longitudinal mixing governs the rapidity with which the lead portion of the effluent moves downstream in advance of the average longitudinal velocity of the stream. According to McKee and Wolf, each stream has unique flow characteristics that govern mixing rates, with stream turbulence, discharge, velocity gradient, slope, depth of flow, channel roughness and configuration, density currents, temperature and wind all being parameters.

Additional mixing concepts of a general nature were explained by these authors. In deep channels of flat slope and with quiescent flow and very little if any turbulence, lateral mixing is inhibited. In some instances, effluent discharge or tributary inflow remains on one side of the main channel for many miles downstream of the point of inflow. In shallow, steep, rough channels, turbulence is high and rapid lateral mixing is experienced. Vertical mixing also occurs rapidly, because of the low ratio of depth to width in most natural channels. Density stratification is frequently experienced in slow moving, deep rivers and in reservoirs, especially when warm effluents or waste discharges inflow at the surface of a river at lower temperatures. Longitudinal mixing was considered to have two effects: (1) it influences the translation of wastes or effluents in the downstream direction, and (2) it may affect the rates of reduction of concentrations or the assimilation of nonconservative substances which are involved in natural stream purification.

2. Longitudinal dispersion

Use of a one-dimensional equation for the conservation of a mass in a flowing stream, for conservative substances such as salt concentrations or other soluble materials, has been made by several researchers (Krenkel and Orlob, 1962; Harleman and Holley, 1962; O'Connor, 1967). Development of this concept has illustrated that the movement of the material, after initial mixing, is a dispersion process with respect to the mean convective motion in the longitudinal direction. The additional longitudinal flux of mass is attributed to the mixing of fluid elements moving with different velocities, primarily because of the vertical distribution of velocity, although horizontal variations in natural channels may also be involved. This has been labeled a diffusion process, and a "diffusion type" coefficient, D_L, introduced as the coefficient of longitudinal dispersion.

In such a simplified analysis, it is assumed that steady, nonuniform, open-channel flow applies, and that the pollutant concentration is a function both of time and longitudinal distance along the length of the channel. The nomenclature used is as follows:

s is the distance coordinate along the channel, or stream, with the downstream direction being positive,

ds is the incremental length along the channel with section 1 at the upstream end of ds and section 2 at the downstream end,

D_L is the coefficient of longitudinal dispersion (L^2/T),

A is the cross-sectional area of the stream (L^2) at any point along the stream,

A' is the average value of A between the end sections,

Q is the total discharge (L^3/T) of the stream, $Q_e + Q_r$,

A'ds is the elemental volume (L^3),

c is the concentration of the potential pollutant, e.g., C_m of Eq. 1 (M/L^3), and

t refers to the time dimension (T).

The transfer rates of the substance into the volume element, A'ds, are described as follows:

Transfer rate across section 1,

$$Qc - D_L A \frac{\partial c}{\partial s} \tag{2}$$

Transfer rate across section 2,

$$- \left[Qc + \frac{\partial}{\partial s} (Qc)ds\right] + \left[D_L A \frac{\partial c}{\partial s} + \frac{\partial}{\partial s} \left(D_L A \frac{\partial c}{\partial s}\right)ds\right] \tag{3}$$

The rate of accumulation of the substance in the volume element,

$$\frac{\partial c}{\partial t} A'ds \tag{4}$$

The conservation of the mass of the substance, assumed to be conservative, requires that the combined transfer rates into the volume equal the rate of accumulation of the substance within the volume. For nonconservative substances, additional differential rates of reaction must be included. If it is assumed that there is no additional inflow into the incremental length, ds, or $\partial Q/\partial s = 0$, and U is defined as the average velocity at any cross section, $U = Q/A$, the combined equation of mass conservation,

$$Qc - D_L A \frac{\partial c}{\partial s} - (Qc + Q \frac{\partial c}{\partial s} ds) + [D_L A \frac{\partial c}{\partial s} + \frac{\partial}{\partial s} (D_L A \frac{\partial c}{\partial s}) ds]$$

$$= \frac{\partial c}{\partial t} A' ds \qquad (5)$$

can be simplified, divided by A'ds as the incremental length ds is permitted to approach zero, and written as

$$\frac{\partial c}{\partial t} + U \frac{\partial c}{\partial s} = \frac{1}{A} \frac{\partial}{\partial s} (D_L A \frac{\partial c}{\partial s}) \qquad (6)$$

If the right-hand term is expanded, the equation becomes

$$\frac{\partial c}{\partial t} + U \frac{\partial c}{\partial s} = D_L \frac{\partial^2 c}{\partial s^2} + \frac{1}{A} \frac{\partial c}{\partial s} \frac{\partial}{\partial s} (D_L A) \qquad (7)$$

As noted by Harleman and Holley (1962), the terms in Eq. 6 have the following significance, left to right: change in c because of unsteadiness, convection of c by the mean velocity of the stream, and transport of c due to longitudinal dispersion. As expanded into Eq. 7, the second term on the right-hand side denotes the difference between nonuniform and uniform flow, in the mass conservation equations. For uniform flow in a stream, $\partial D_L/\partial s = 0$ and $\partial A/\partial s = 0$, leaving the first three terms of Eq. 7 for application.

Solution of Eq. 6 or Eq. 7 depends upon the initial and boundary conditions which apply to a specific problem. If the effluent, upon discharge and initial mixing, were to move as a slug (the commonly assumed plug-flow concept), then $s = Ut$ and the solution of Eq. 6 or 7 would indicate no change in the concentration of a conservative substance with either time or distance (constant temporal and spatial concentration). Equation 1 would then apply at all points in the stream. Equations 6 and 7 illustrate that a more complex nature of the stream environment may exist.

Two dimensional equations actually should be considered, as outlined by Thomas and Archibald (1952), but it has been noted that solution of such equations is much more difficult (Harleman and Holley, 1962). Both two and three dimensional dispersion equations have been proposed for estuary conditions (Diachishin, 1963; Patterson and Gloyna, 1965; Fischer, 1967). McKee and Wolf (1963) concluded that in view of the many factors which discount the assumptions required, the complex formulas lose their practical significance in natural streams. Sedimentation, chemical actions, adsorption, density currents, etc. were complicating factors listed. It was their hope that all of these complications could be included in more simple empirical formulation of the reactions occurring in the stream environment.

3. Stream velocities and time of travel

Time is easily introduced as a variable in developing mathematical models of stream behavior. However, time by itself provides no knowledge of the spatial location of computed or simulated reactions. The physical relationship between distance and time, as outlined in the previous section, is expressed in terms of the average stream velocity, U, for specified discharges or related stages.

The average stream velocity at selected points can be determined using current meter measurements (Linsley et al., 1949; Chow, 1964). Frequently, current meter measurements taken by the U.S. Geological Survey in the water resources data program can be obtained, from which the average velocity can be extracted or computed (U.S. Geological Survey, 1968). However, the techniques of measurement at low-flow periods usually dictate that a section be used in which the velocity is a maximum for the reach. The average velocity so obtained may not be representative of the actual time of travel through a pool-riffle-pool sequence usually encountered in natural streams.

Volumetric and discharge relationships were used in early studies, and the techniques explained by Velz (1958). Cross sections are usually taken at least every 500 ft or less, and the channel volume determined using the average-end method. The velocity is computed from the area-volume-discharge relationships, with the discharge being measured at selected points or derived from data obtained at normal gaging station sites. As noted by Velz, these techniques have worked best in large streams with substantial depth of flow which permitted the use of echo sounding devices.

Tracer techniques have been perfected in the last decade, and are being used extensively today (Straub et al., 1958; Feuerstein and Selleck, 1963; Buchanan, 1964; Wright and Collins, 1964; Gannon, 1966; Purdy, 1966; Stewart, 1967; Bauer, 1968; Wilson, 1968). Fluorescent dyes have proven to be most effective and useful, and elaborate directions prepared for their use (Wilson, 1968). Concentrations of dye as low as 0.05 part per billion (ppb) can be measured quantitatively with commercial fluorometers. Dye is usually injected as a slug at an initial point, or points, and samples taken subsequently at downstream points for analysis of concentration levels. A method of computing the initial dosage was given by Buchanan (1964), based upon a desired 1 ppb concentration in the volume of water contained in the study reach. The approximate dosage was computed as

$$\text{Volume} = \frac{Q}{U} L \qquad (8)$$

where

V = volume of dosage, in cubic feet,

Q = discharge, cfs,

U = estimated average stream velocity, from float measurements or other techniques, fps,

L = length of reach, ft.

Samples are taken at periodic intervals at all downstream stations, the dye concentrations measured, and concentration hydrographs drawn. Important parameters obtained through this analysis include the time of initial or first appearance of the dye cloud, the time of peak concentration, the centroid time value, time of one-half of the hydrograph (time at which one-half of the material has passed the station), and an estimate of the end or tail of the hydrograph (usually taken as the 10% peak value). Time of travel curves can be plotted with the data, and for known or measured discharges, the relationship of time of travel to discharge can be determined. The simple mathematical model obtained by Bauer (1968) was of the form

$$T = aQ^{-b} \tag{9}$$

where

T = time of travel, in hours or days,

Q = discharge of the stream, in cfs, and

a and b are coefficients obtained from graphical or analytical analysis.

Because s = Ut, the relationship between the average velocity of the stream, U, and discharge, Q, can be expressed mathematically.

C. Biological Oxidation of Organic Wastes

1. Results of early laboratory studies

According to Phelps (1944), aerobic decomposition directly involves atmospheric oxygen or its equivalent, with organic matter being oxidized and oxygen reduced. Theriault (1927) summarized the results of early experiments conducted to determine the oxygen demand of polluted waters. In the late 1800's, according to this summary, Sir Edward Frankland, in England, and Gerardin and Dupre, in France, studied the oxidation process using polluted river waters. Frankland reported in 1870 on the orderly manner in which oxidation of polluted river water, stored in a sealed bottle, progressed but he believed it to be purely a chemical reaction. Gerardin observed dissolved oxygen levels in the Seine River downstream of Paris and by 1875 had reported on the oxygen depletion and recovery of the river. Dupre, in an 1884 report, recognized the activity of living organisms and noted that without them little or no oxygen was consumed. Later, Adeney and his followers, through the auspices of the Royal Commission on Sewage Disposal, developed quantitative techniques for measuring the oxidation rates, and pointed out the significance of oxygen depletion values as measures of stream pollution. The laboratory 5-day bottle incubation technique which they developed permitted the oxygen loss to be determined, and this loss was designated as the "dissolved oxygen absorbed in 5 days at 65 deg F."

The reduction of the dissolved oxygen content in water containing organic wastes was attributed by Adeney's group to three mechanisms:

> "a. simple dilution with deaerated water, from waste water or tributaries,
>
> b. rapid reduction by directly oxidizable substances, a chemical reaction, or
>
> c. slow reduction by organic constituents and ammonium compounds."

McGowan (Theriault, 1927) expressed the ultimate oxygen demand (UOD) quantitatively as:

$$UOD = 4.5\ (A + O) + 2\ V \qquad (10)$$

where

UOD = ultimate oxygen demand of the organic waste, mg/l,

A = ammoniacal nitrogen, mg/l-N,

O = organic nitrogen, mg/l-N, and

V = volatile matter in suspended solids, mg/l.

The 5-day, 65 deg F BOD test was used by McGowan in England to provide a means of classifying stream conditions, relating the BOD values and selected physical characteristics. Stream conditions were classified according to BOD values as: very clean, 1 mg/l; clean, 2 mg/l; fairly clean, 2.7 mg/l; moderate, 3.1 mg/l; doubtful, 4.8 mg/l, and bad, 9.7 mg/l or greater.

These developments led to similar BOD studies in the United States. Theriault (1927) reported that two laboratory standards were in consideration in the early 1910's, 20 deg C and 37 deg C. Through intensive laboratory studies (Theriault and Hommon, 1918), the effects of dilution, temperature, nature of dilution water, bottle incubation and sealing techniques were determined and standard laboratory methods recommended. The temperature value of 20 deg C was selected to conform more nearly with observed stream conditions. These techniques were incorporated subsequently in Standard Methods (1965) as the recognized method of conducting BOD tests. The BOD test remains the principal measure of the pollutional strength of organic wastes.

The existence of two stages in long-term BOD studies became evident to Adeney and his researchers, as reported by Theriault (1927). Periods up to 50 days in length were analyzed, and the characteristic two-stage BOD curve was first evidenced. This second stage was attributed to nitrification, starting at about the tenth day for raw or diluted raw sewage. McGowan developed Eq. 10 from his analysis of both the carbonaceous and nitrification oxygen demands. The two-stage BOD curve is illustrated in Fig. 1.

The average per capita total first-stage oxygen demand (carbonaceous portion) was also a matter of research during this period. As reported by Theriault (1927), studies of waste loads and strengths of sewage from major cities were made by Mohlman, Phelps and Frost. Values were obtained ranging from 0.22 to 0.27, with an average of 0.24 lb per capita per day (pcd). Later studies yielded 5-day values of 0.10 to 0.12 pcd, with a total first-stage demand of 0.15 to 0.22. At Baltimore, Maryland, and Columbus, Ohio, values of 0.24 and 0.25 pcd were obtained. Theriault (1927) concluded that the values would vary according to industrial loads and other factors, and tabulated general results for field application as: strictly domestic sewage, 0.17 to 0.18 pcd (BOD, 5-day, 20 deg C); combined sewage, domestic and industrial, 0.24 pcd; and with large amounts of industrial wastes, 0.4 to 0.5 pcd.

2. Mathematical formulation of the carbonaceous oxygen demand

a. The first-order reaction   Theriault (1927) credited Phelps as the first to apply mathematical analysis to the observed BOD phenomena represented by the first-stage carbonaceous oxygen demand. It was noted (Streeter and Phelps, 1925) that the biochemical reaction was orderly and consistent, progressing at a measurable rate. The concept of the monomolecular or first-order chemical reaction was adopted to represent the oxidation of organic material, assuming

> "the rate of biochemical oxidation of organic material is proportional to the remaining concentration of unoxidized substances, as measured in terms of oxidizability."

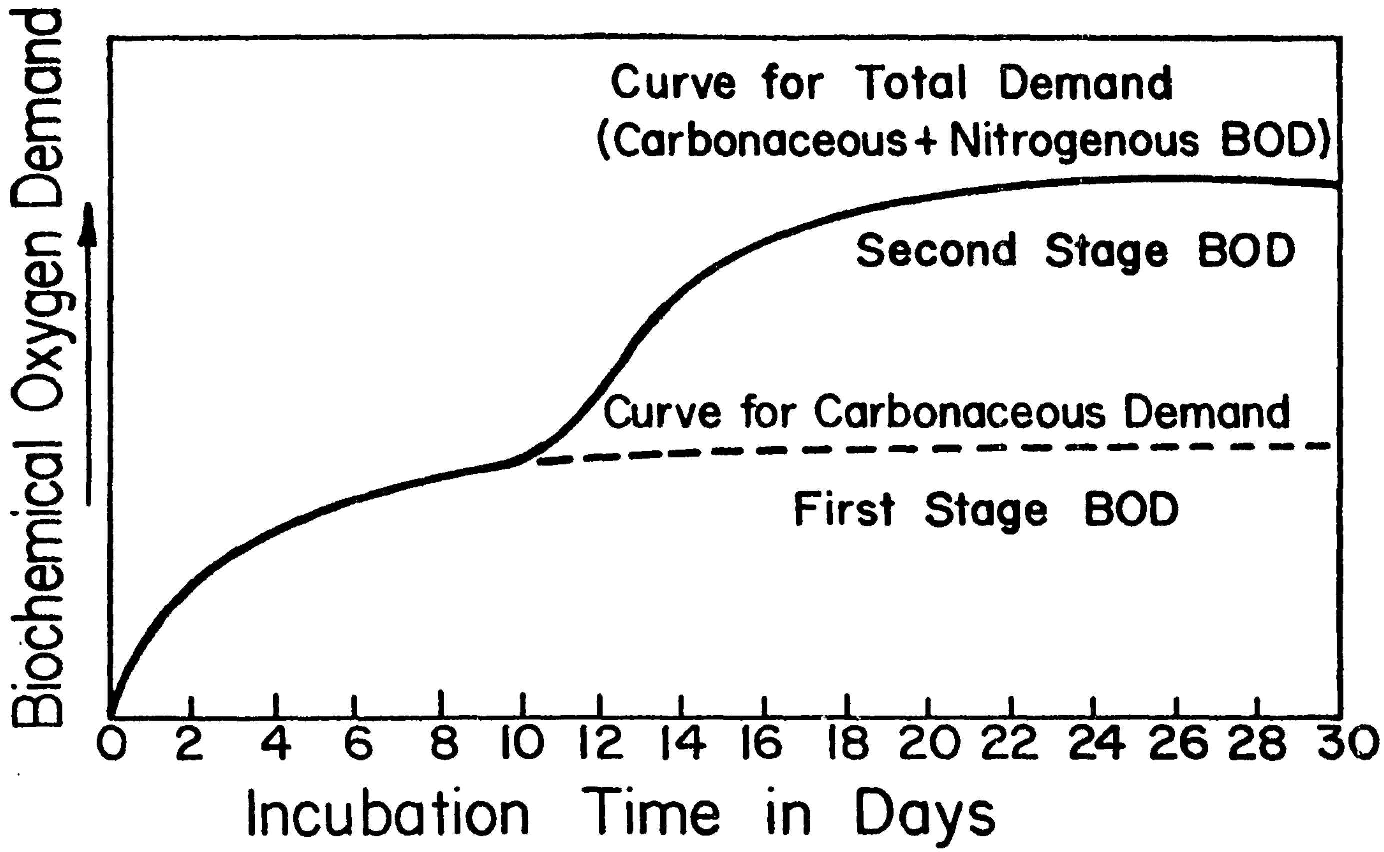

Fig. 1. The two-stage curve for biochemical oxygen demand.

In the form of a differential equation, the rate is expressed as

$$- \frac{dL}{dt} = kL \tag{11}$$

where

L = carbonaceous oxygen demand of the organic substance, mg/l, at any time,

k = rate or velocity coefficient, defining the rate at which the reaction proceeds, per day (day^{-1}), hereafter called the deoxygenation coefficient, and

t = elapsed time, days.

The initial condition commonly used is $L(t = 0) = L_a$. Integration of the differential equation yields, using exponential notation [$\exp(- kt) = e^{-kt}$],

$$L = L_a \exp(- kt) = L_a 10^{-K_1 t} \tag{12}$$

where

L_a = ultimate first-stage oxygen demand, mg/l, of the oxidizable matter initially present, and

K_1 = 0.434 k, per day (base 10).

The oxygen uptake, or BOD exerted from t = 0 to any time, t, is expressed as

$$y = L_a - L = L_a[1 - \exp(- kt)] = L_a(1 - 10^{-K_1 t}) \tag{13}$$

A complex method for determining the deoxygenation coefficient (k or K_1) from laboratory data of BOD progression was developed by Theriault (1927) using the method of least squares. Once the coefficient was determined by statistical means, L_a could be computed using Eq. 13.

An average value of 0.10 for K_1 (20 deg C) was adopted in the early studies of both river pollution and of domestic sewage, although variations were noted (Streeter and Phelps, 1925; Theriault, 1927). It was observed that the deoxygenation coefficient was a function of temperature and of the character of the waste organic matter, as evidenced under actual stream conditions. Temperature corrections, based upon the results of several research studies, were formulated as

$$\frac{k_T}{k_{20}} = \theta^{T-20} = 1.047^{T-20} \qquad (14)$$

where

k_T = deoxygenation coefficient at any temperature, T, in units of per day,

k_{20} = corresponding rate at 20 deg C, per day,

θ = thermal coefficient, evaluated as 1.047, an average value of several studies, and

T = temperature corresponding to k_T, in deg C.

The effect of temperature upon the ultimate first-stage oxygen demand was formulated (Theriault, 1927; Phelps, 1944) as:

$$(L_a)_T = (L_a)_{20}[1 + 0.02(T - 20)]$$

$$= (L_a)_{20}\,(0.02\,T + 0.60) \qquad (15)$$

where

$(L_a)_T$ = value of L_a at any temperature, T,

$(L_a)_{20}$ = value of L_a evaluated at 20 deg C, and

T = temperature corresponding to $(L_a)_T$.

However, Theriault (1927) discussed variations which had been observed in the 2% value accepted for the temperature variation, and noted that values up to 4% had been recorded. Equation 15 has been included in all reference work and sanitary engineering texts through the 1950's (Fair and Geyer, 1954; Babbitt and Baumann, 1958). However, research work by Gotaas (1949) indicated that the variation with temperature could not be justified, and Eq. 15 was omitted in one recent textbook (Fair et al., 1968).

Various methods have been developed for obtaining time-average values of the deoxygenation coefficient, k, and the ultimate first-stage oxygen demand, L_a, for a time series of values of BOD. Equation 13 contains two unknowns, k and L_a; therefore, a single observation (such as BOD_5) yields no quantitative information about either unknown, despite the initial condition of y = 0 at t = 0. A minimum of two observations in a time series is required to yield singular solutions for k and L_a. A time series of values of y extending over a period of several days or more provides data from which the two unknowns can be evaluated, for time averages of k and L_a.

The test of appropriateness which was adopted by Theriault (1927) for acceptance of the first-order reaction was its ability to predict laboratory results, using as a standard the statistical concept of minimizing the variance. He then developed a method using least squares. A much easier method was introduced by Thomas (1950), based on the mathematical similarity of the expansion of $(1 - e^{-kt})$ to the function $kt/(1 + kt/6)^3$. Appropriate transformation produced the function

$$\left(\frac{t}{y}\right)^n = \frac{1}{(L_a k)^n} + \frac{k/6}{(L_a k)^n}(t) \qquad (16)$$

where

$n = 1/3$, and other terms are as previously defined.

The transformation results in a linear function of the type $Y = a + bX$. Values of t and y permitted either graphical solution of the linearized equation, or analytical solution through linear regression. Values of k and L_a were obtained subsequently from the coefficients a and b.

The method of moments was the third method introduced for obtaining values of k and L_a from observed BOD data. This method assures that the computed BOD values will have the same first and second moments (BOD versus time) as that existing for the time series of observed BOD values. The mathematical model for the method of moments (Moore et al., 1950) included two formulas. For the first moment,

$$\sum_{i=0}^{n} y_i = \sum_{i=0}^{n} L_a[1 - \exp(-kt_i)] \qquad (17)$$

and for the second moment

$$\sum_{i=0}^{n} t_i y_i = \sum_{i=0}^{n} L_a t_i [1 - \exp(-kt_i)] \qquad (18)$$

where

y_i = observed BOD exerted in time t_i, mg/1,

t_i = elapsed time since BOD analysis began, days,

n = number of observations, and

L_a and k were previously defined.

Division of the first equation by the second eliminates the term L_a, assumed as constant, and the only variable remaining as an unknown is k. The value of L_a is obtained by solving Eq. 17, using the computed value of k. Type curves were developed by Fair and Geyer (1954) to assist in obtaining a solution for k, since division of Eq. 17 by Eq. 18 produces a result which cannot be solved directly for k, but requires trial and error calculations.

The first-order mathematical model for BOD progression reportedly provides an accuracy within 10% (Babbitt, 1953) between observed and computed values. A comprehensive study of the three methods of computing the deoxygenation coefficient, k, and the ultimate BOD value, L_a, indicated that the method of moments was preferred (Ludzack et al., 1953). A smaller value of variance was obtained than by either of the other methods, for wastes having three ranges of deoxygenation coefficient values, low (0.07 to 0.12), intermediate (0.12 to 0.16), and high (0.16 to 0.32). The ease of calculation favored the method of moments, also.

Additional study of the progression of BOD with time (Orford et al., 1953; Orford and Ingram, 1953; Woodward, 1953; Busch, 1958; Schroepfer et al., 1960) have shown that the deoxygenation coefficient, k, can depart considerably from the value of 0.23 (K_1 = 0.10) which had been adopted originally for domestic sewage. Variations of both k and L_a with respect to the time period of analysis as well as with respect to type of waste were noted. As the time period of analysis is increased, the average value of k or K_1 decreased, but the average value of L_a

increased. Typical values obtained by Orford et al. (1953) for a waste from an intensively developed housing unit were:

Selected time interval, days	Values of coefficients K_1, per day	L_a, mg/l
3	0.40	276
5	0.32	302
7	0.29	315
10	0.24	335
14	0.20	353

Orford and Ingram (1953) reported that for normal domestic sewage, a value of 0.25 for K_1 was obtained in a 3-day analysis, but only 0.11 in a 14-day analysis. The corresponding value of L_a increased from 90% of the 5-day BOD for the 3-day period to 140% of the 5-day BOD for the 14-day period.

b. The second-order reaction These inconsistencies have caused other mathematical models to be proposed. A logarithmic formula was proposed as being superior to the first-order reaction (Orford and Ingram, 1953). However, Woodward (1953) demonstrated that a second-order equation first introduced by Thomas was superior to the logarithmic form. The differential equation for the second-order relationship is

$$\frac{dy}{dt} = k'(L_a' - y)^2 \tag{19}$$

which integrates to

$$y = \frac{k'(L_a')^2 t}{1 + k'(L_a')t} \tag{20}$$

for the initial condition y(t = 0) = 0, and where

y = BOD uptake, as defined before, mg/l,

k' = deoxygenation coefficient for second-order model, per mg/l per day,

L'_a = ultimate first-stage oxygen demand for the second-order model, mg/l, and

t = elapsed time in days.

Woodward (1953) introduced the additional relationship, $k'' = k'L'_a$, to obtain

$$y = (L'_a) \frac{k''t}{1 + k''t} \tag{21}$$

where

k'' = modified deoxygenation coefficient, per day.

The second-order mathematical model was used by Young and Clark (1965) and found to be superior to the first-order model.

c. Requirements for any mathematical model The primary attributes that any mathematical model of BOD progression must possess have been stated by Imhoff and Fair (1929) to be:

a. a limiting or ultimate value of oxygen consumed, and

b. a rate constant of proportionality per unit of time.

Both the first-order and second-order mathematical models (Eqs. 13 and 21) meet this requirement, as illustrated by Fair and Geyer (1954) with each having an asymptotic value of the ultimate oxygen demand (L_a or L'_a, respectively) as time increases without bound and a rate constant (k or k''), per day.

3. Mathematical expression of the nitrogenous oxygen demand

a. The oxidation of nitrogenous waste products   The biochemical oxidation of organic nitrogen contained in domestic, municipal and certain industrial wastes was shown previously to occur in three stages. Organic nitrogen is oxidized successively to ammonia, nitrite, and nitrate. Stoichiometrically, if each is measured in terms of N-nitrogen, the second step requires 3.43 mg/l of oxygen (ammonia to nitrite), the third step requires 1.14 mg/l of oxygen (nitrite to nitrate), with a total of 4.57 mg/l of oxygen required to oxidize each mg/l of combined organic and ammoniacal nitrogen to the fully oxidized state. Conversion of organic nitrogen to ammonia is not usually evaluated in terms of oxygen demand, and the organic portion is included with the ammonia for computation purposes. The full oxygen demand may never be required completely (less than 100% exertion) because of the complex biological processes involved in breaking down the organic nitrogen in wastes and its subsequent utilization in cell protoplasm of the nitrogenous bacteria. A total of 4.33 mg/l was the maximum exertion reported in one recent study of nitrification rates (Gannon and Wezernak, 1967), or 95% of the stoichiometric value. As previously noted, in the stream environment some algae can use ammonia as a source of nitrogen, so competition between the algae and the nitrogenous bacteria may exist.

Table 1 indicates that from 15 to 50 mg/l of ammonia are contained in raw sewage (as free ammonia), or 12 to 41 mg/l as N-nitrogen. The equivalent oxygen demand is from 55 to 180 mg/l, illustrating a nitrogenous BOD of more than 50% of the average carbonaceous BOD_5 of raw sewage. The requirement and associated percentage would be greater if organic nitrogen were included.

b. <u>A first-order reaction for nitrogenous BOD</u> Streeter, in several studies of stream pollution (1935a, 1935b), introduced a mathematical model for the observed two-stage BOD relationship which included both the carbonaceous and nitrogenous oxygen demand. Formulation of this model was based on summer and winter studies of the Illinois River during the period 1927-1930. The concept of the first-order reaction was introduced for each and the resulting linear combination was obtained:

$$y = L_c(1 - 10^{-K_c t}) + L_n[1 - 10^{-K_n(t-a)}] \qquad (22)$$

where

y = total oxygen uptake, mg/l, exerted up to the time, t,

$L_c = L_a$ for carbonaceous matter, mg/l (as previously defined),

$L_n = L_a$ for nitrogenous matter, mg/l,

K_c = deoxygenation coefficient for first-stage BOD, per day, base 10,

K_n = deoxygenation coefficient for second-stage BOD, per day, base 10,

t = elapsed time in days since analysis began, and

a = time at which the second stage is assumed to begin exerting its oxygen demand at the first-order reaction rate, in days (a lag concept).

Streeter reported values of 0.103 and 0.031 for K_c and K_n for the Illinois River.

This first-order reaction for nitrogenous oxidation was used in studies of stream behavior by Courchaine (1963). Effluents were obtained from an activated sludge plant (Lansing, Michigan), and from the receiving stream. In the effluents, organic and ammonia nitrogen were in the range of 15 to 25 mg/l N-nitrogen. Nitrites and nitrates were very low. Laboratory analysis of the effluent and stream samples provided data that indicated a lag period of about 9 days (parameter a in Eq. 22), with nitrification being completed in an additional 10 days. In one instance, however, nitrification of a stream sample began under laboratory conditions after 4 days. A study of the extraction rate of the stream, in a reach where a thermal plant discharged cooling water, showed that 2/3 of the nitrogenous demand (measured at the beginning of the reach) was exerted in less than 1 day's travel time. All of the laboratory tests showed that 70 to 80% of the total first- and second-stage BOD (ultimate demand of each) occurred as nitrogenous BOD, both for the effluents and the stream. This indicates that waste treatment can effectively reduce the carbonaceous matter, but the nitrogenous load remains high.

For trickling filter plans, Sawyer and Bradney (1946) illustrated that the effluents were well into the nitrification stage, thus indicating that the lag, a, could reduce to a zero value for this secondary treatment process. Morris et al. (1963) reported on an extended aeration plant, with the results indicating a normal 10-day lag for plant influent, but ranging from 0 to 2 days for the effluent. O'Connell and Thomas (1965) studied the effects of a trickling filter effluent on the Truckee River in Nevada. Stoichiometric calculations were used to determine the effects of the nitrogenous oxygen demand, and approximately 6 mg/l of dissolved oxygen were required for nitrification in the reach studied. The amount of dilution, stream versus effluent, was not given. By comparison, Courchaine (1963) reported 12 to 16 mg/l of nitrogenous BOD in river samples obtained below the outfall of an activated sludge plant, illustrating that the total demand can exceed the amount of dissolved oxygen normally contained in the stream. With an observed value of 93 mg/l for the nitrogenous BOD in the effluent prior to discharge, the need for dilution water and good assimilative and reaeration capacity is indicated. Courchaine's data indicated that the nitrogenous BOD exerted in the stream was 8,000 lb in a travel time of 0.7 days, with an observed stream discharge of 254 cfs. This yields a value of 8.3 mg/l of oxygen demand upon the stream in the reach traversed in the given time.

c. Other factors influencing nitrification Other parameters have been studied to determine their effect upon the rate of nitrification. Temperature, the level of dissolved oxygen concentration, pH, and acclimatization of nitrifying organisms. Two factors of greatest concern in stream pollution studies are the most favorable temperature range for nitrification to proceed and the observed inhibiting of nitrification at either low temperatures or low dissolved oxygen concentrations. Metabolic reactions have been reported for these nitrifying organisms (Buswell et al., 1950, 1952; McKinney, 1962; Courchaine, 1963) with the optimum temperature range being above 25 deg C. Although the range 25 to 28 deg C is commonly reported as optimum, Buswell found optimum oxidation of ammonia at 32 deg C in laboratory tests. When temperatures fall to as low as 5 deg C, nitrification has been severely if not completely inhibited. Theriault et al. (1931) observed that nitrification was inhibited at dissolved oxygen concentrations of less than 2 mg/l. In the activated sludge process, Fair et al. (1968) note that with DO levels approaching 1 mg/l, little if any nitrification will be expected in the effluent. Recent work in England indicates that a rapid reduction in the rate of nitrification can be expected with oxygen levels below 3 mg/l (Water Pollution Research Laboratory, 1964).

More theoretical mathematical models of nitrification behavior have been proposed in the last few years. Stratton and McCarty (1967) constructed a laboratory river model for developing a method of forecasting nitrification based upon the modern concepts of biological kinetics which have been introduced to describe the rate of growth of biological organisms. These equations require knowledge of the bacterial mass in addition to the concentration of substrate (nitrogen compounds in this case). Gannon and Wezernak (1967) used a more simplified equation of the enzyme reactions which have been classified as the Michaelis-Menton relationships (Fair et al., 1968). Because of the assumptions and approximations required in each, and the additional complicating factors observed in natural streams (including the mass of algae which will not be involved in the nitrification process, but which can hardly be separated from the bacterial mass), these more advanced methods were not included in this study.

The temperature coefficients obtained by Stratton and McCarty (1967) for the substrate utilization constants (somewhat similar to the deoxygenation coefficients of Eq. 22) for nitrification do indicate the more rapid effect of temperature upon the process. The temperature coefficient for ammonia, similar to θ in Eq. 14, was 1.088 and for the nitrite to nitrate conversion it was 1.058, greater than the 1.047 obtained for the carbonaceous oxidation role. As explained by Courchaine (1963),

> The rate of oxidation of carbonaceous matter like that of nitrification is also dependent upon multiplication of bacteria; however, the lag phase which is experienced in nitrogenous BOD is usually not pronounced in the first stage BOD curve. The reason for this can be explained by comparing the organisms responsible for the oxidation of carbonaceous matter with those which carry out nitrification. Most bacteria obtain their food and energy requirements from organic matter. These bacteria are known as heterotrophs and are the bacteria which carry out the oxidation of carbonaceous material in the first stage BOD reaction. They consist of a great variety of individual types of bacteria with optimum temperatures ranging from 18 to 25 deg C. Generation time varies with species; however, it is relatively short, ranging from 20 to 30 minutes for many of the bacteria in this group. A single organism with a generation time of 30 minutes could produce about 300 billion new cells within a 24-hour period.
>
> The oxidation of nitrogenous matter on the other hand is carried out by specific bacteria which obtain their food and energy from oxidation of ammonia and nitrite nitrogen. These bacteria which utilize inorganic compounds in their metabolism are classed as autotrophic bacteria. The nitrifying organisms Nitrosomonas and Nitrobacter have optimum temperatures for growth of 25 and 28 deg C, considerably higher than the usual 20 deg C temperature used in the standard BOD incubation. An important factor, insofar as the time of onset of nitrification in the BOD test, is the relatively long generation time of the nitrifying organisms. Buswell and his co-workers found the generation time for nitrifying cells to be about 31 hours.

Therefore, temperature plays a greater role for the specific nitrifying bacteria, and the coefficients obtained by Stratton and McCarty, although developed for more refined mathematical models, serve as a first approximation of the temperature effect for the nitrogenous portion of Eq. 22.

4. Uniform contributions of BOD along a stream

Streeter and Phelps (1925), in developing the first mathematical model for describing the oxygen sag curve, gave consideration to the problem of inflowing pollution (or its converse, inflowing dilution) occurring uniformly between two sampling points. This assumption of a uniform distribution of inflow (or dilution) was considered applicable also for closely spaced points of equal loading. The nomenclature for this formulation, as modified for this study, is as follows:

L_t = increase (or decrease for dilution) in BOD produced up to the time t by uniformly distributed increments of inflow, mg/l or lb,

p = an incremental increase (or decrease) in BOD, per unit of time, inflowing to the stream and producing an effect equivalent to L_t at time, t, in mg/l per day or lb per day,

k = deoxygenation coefficient, per day,

t = elapsed time of flow, days,

dt = small increment of time, t, in days (increment of a day),

L_A = value of L_a observed at sampling point A, and

L_B = value of L_a observed at sampling point B.

The method of increments was employed in order to determine an expression for L_t in terms of p. It was assumed also that the value of L_t would remain constant for each small increment of time, dt. Such a procedure

yielded

$$\text{for } t = 0;\ L_t = 0$$

$$t = dt;\ L_t = p(dt)$$

$$t = 2dt;\ L_t = p(dt)\left\{1 + \exp[-k(dt)]\right\}$$

$$t = 3dt;\ L_t = p(dt)\left\{1 + \exp[-k(dt)] + \exp[-k(2dt)]\right\}$$

......

......

$$t = n(dt);\ L_t = p(dt)\left\{1 + \exp[-k(dt)] + \exp[-k(2dt)] + \cdots + \exp[-k(n-1)(dt)]\right\}$$

This progression was shown to be equivalent to

$$L_t = \frac{p(dt)[1 - \exp(-kt)]}{\left\{1 - \exp[-k(dt)]\right\}} \qquad (23)$$

Streeter and Phelps (1925) permitted the use of $dt = 1$, thus further simplifying the equation. In addition, for values of $k(dt)$ smaller than about 0.2, the quantity $\left\{1 - \exp[-k(dt)]\right\}$, being a constant value in regard to time, t, can be replaced with the value $[k(dt)]$, the error being about 10% for the given value, 0.2, and less for smaller values. This can be achieved in stream pollution studies by selecting a value of (dt) that will provide the desired degree of accuracy, when combined with an observed value of k. This simplification yields

$$L_t = \frac{p}{k}[1 - \exp(-kt)] \qquad (24)$$

The total amount of carbonaceous BOD which would be contained in a volume of stream water downstream from an initial point of discharge and with additional inflow was shown (Streeter and Phelps, 1925) to be, for any time, t,

$$L = [L_a \exp(-\ kt) + p \frac{1 - \exp(-\ kt)}{1 - \exp(-\ k)}] \tag{25}$$

Equation 25 can then be substituted in Eq. 11 for integration, or in the differential equation for dissolved oxygen depletion.

If the two carbonaceous demands contained in Eq. 25 are the only ones exerting an oxygen demand upon the stream between points A and B, and the values of L_a were determined from laboratory analysis at each point, then the assumption can be made that

$$L_t = (L_a)_B - (L_a)_A \exp(-\ kT) \tag{26}$$

where

T = time of travel between sampling stations A and B.

Thus, L_t was supposed to account for the difference between the observed reduction of BOD in the reach and that computed from Eq. 12, in terms of the ultimate BOD. Appropriate substitutions in Eqs. 24 and 26 would then permit the value of p to be computed for a given reach.

Because of the additional mathematical complexities involved, Streeter and Phelps did not advocate general use of the combined equation shown as Eq. 25. The Ohio River, which was used in illustrating the effective use of the derived mathematical models for oxygen uptake and stream dissolved oxygen deficits, contained several low head navigation dams, many point sources of pollution, etc., and the simplifying assumption of uniform distribution of either inflow or dilution was a second factor leading them not to favor its inclusion at that time.

Worley et al. (1965) reintroduced this concept in developing a mathematical model for the dissolved oxygen deficit in studies of the

Willamette River basin in Oregon. The parameter, B_L, was defined as the bank load, a uniform oxygen demand by such things as tree leaves, etc., that could enter the stream along its banks. In the terminology of Eqs. 23 to 26,

$$B = \frac{B_L(24U)}{k} = \frac{p}{k} \tag{27}$$

where

B = bank load BOD measured in the stream, mg/l,

B_L = bank load BOD contribution, mg/l/mile,

U = stream velocity, mph, and

k = deoxygenation coefficient for the river, per day,

for small values of k, and with additional constants to place B_L on a per mile basis rather than per day, using the mean velocity of the stream, U, in the conversion. Camp (1965) adopted a similar technique but considered p to represent the rate of addition of BOD to the overlying water from the bottom deposits, in mg/l per day.

5. Organic sludge deposits

During the 1800's and the first half of the 1900's, when raw sewage and industrial wastes were discharged to streams with little or no treatment, sludge deposits were of major concern. Phelps (1944) provided a descriptive account of the sedimentation process and resulting accumulation of solid organic matter as sludge on the bed of a stream. It was well emphasized that this accumulation could exert a considerable influence on the oxygen balance of the stream. Slackwater stretches in natural pools, and upstream of milldams, were labeled as the reaches first and primarily affected. Velz (1958) identified three types of deposits which could lead to unsightly conditions and to depression of the dissolved oxygen profile. The settleable solids, flocculation and coagulation of suspended and colloidal particles, and biological extraction of dissolved organics all lead to the formation of deposits.

Streeter (1935a) used the method of increments described in the previous section to develop an expression of the oxygen demand of sludge deposits. The mathematical model was of the form

$$y' = p_d \frac{(1 - 10^{-K_d t'})}{2.3\ K_d} \tag{28}$$

where

y' = accumulated BOD in lb,

p_d = the daily contribution to the sludge deposit, in lb of BOD per day,

K_d = the specific rate of oxidation of the deposit, or a deoxygenation coefficient, per day, base 10, and

t' = the time during which the accumulation has taken place, in days.

Streeter obtained values of K_d ranging from 0.03 to 0.05, at 25 deg C. This value of K_d yields a value of (2.3 x K_d x 1 day) of less than 0.11, permitting the transformation from Eq. 23 to Eq. 24, and subsequent development of Eq. 28. The daily oxygen demand for this model, for a K_d value of 0.03, was noted by Velz (1958) to be about 7% of the amount remaining from the previous day, and that about 40 to 50 days were required for the pile to reach equilibrium.

Velz (1958) outlined the specific model manipulating techniques required when the effect of sludge deposits was to be included in BOD exertion. A truckload population equivalent concept was introduced. A total of six variations in the temporal accumulation of the deposit and its resultant effect on the oxygen resource of the stream, were noted to exist. These would affect the actual value of L_d to be used at a particular time, t'. The maximum daily demand was determined from the equilibrium BOD value of the sludge deposit, or 7% of $p_d/2.3\ K_d$. Variations in the accumulated amount could exist, from the first day's accumulation to the equilibrium BOD value reached in 40 to 50 days. The additional variations encountered would depend upon such occurrences as interruption of deposition, sudden and complete scour, dormancy due to cold weather (using Eq. 14 to vary the deoxygenation coefficient) and increased activity due to increased temperatures.

From field observations and evaluation of time of travel curves, Velz determined that the critical velocity below which solids definitely would settle out on the stream bottom was 0.6 fps. Because of decomposition activity and gradual compaction of sludge over a period of time, the velocity required to rescour the accumulated deposit back into suspension was reported to be from 1.0 to 1.5 fps. Examination of time of travel curves at various discharge levels showed where deposits might be experienced, and also at what discharge levels rescour could again be expected.

Because sludge deposits exert their influence at a fixed location in the stream, the reactions cannot be included in mathematical models which relate to the flowing water (plug-flow). <u>The "truckload" technique</u>

of Velz (1958) appears to be the optimum method for including sludge deposits as a variable. Population equivalents are used in the truck-load conveyance concept. Effluents from water pollution control plants are divided into two components, (1) the colloidal and dissolved solids, and (2) the settleable solids. If both remain suspended, the BOD in population equivalents (PE) is reduced by the decay rate expressed by Eq. 12. At the first point where the average stream velocity, U, is less than 0.6 fps, the settleable solids are presumed to form sludge beds. A running account can be maintained of the daily sludge accumulation, and of its daily oxygen demand upon the dissolved oxygen resource at that point. The colloidal and dissolved fraction is permitted in the computations to proceed downstream, again being reduced according to Eq. 12. By maintaining a running account of these several carbonaceous BOD sources, as liabilities, and including the initial oxygen resource and additional reaeration, Velz was able to compute stepwise the dissolved oxygen levels in the stream, in addition to the level of BOD remaining at any point.

The additional effects of temperature, pH, sludge depths, etc. must also be included, as first summarized by Phelps (1944). However, with the recent edict issued by Agee and Hirsch (1967), which specifies secondary treatment as the minimum acceptable treatment level (with 90 to 95% removal of suspended solids), the problem of sludge deposits may not be as important as it was in the past.

6. Determination of river deoxygenation rates

The coefficient of deoxygenation for carbonaceous oxidation (k, base e; K_1, base 10) determined through laboratory analysis can be referred to as a "bottle k." For stream water samples, values of L_a can be evaluated through laboratory analysis of oxygen uptake, as well as bottle k's, of a time series of samples from successive sampling stations in the downstream direction. In studies of the reaction rates for rivers (Thomas, 1948; Streeter, 1958; McKee and Wolf, 1963), the "river k" has been determined using the relationship

$$K_r = \frac{1}{t} \log \frac{L_A}{L_B} \quad (29)$$

which was derived from application of the first-order reaction of Eq. 12 as a representation or simulation of the BOD consumed during the time of travel between sampling stations A and B, or

$$L_B = L_A(10)^{-K_r t} \quad (30)$$

where

K_r = computed coefficient of deoxygenation, the "river k," base 10, per day,

L_A = value of L_a at the upstream sampling station, as determined from laboratory studies, mg/l,

L_B = value of L_a at the downstream sampling station, mg/l, and

t = elapsed time of travel between the stations, days.

By plotting values of L_A and L_B on semi-log graph paper for corresponding values of time, the river K_r value can be determined.

The difference between the values of K_1 (the bottle k) and K_r (the river k) were designated (McKee and Wolf, 1963) as K_3, or

$$K_3 = K_r - K_1 \tag{31}$$

with the value of K_3 being positive if K_r exceeded K_1, and negative if K_1 were greater.

Purdy (1966) referred to K_r as the overall extraction rate for the stream. Those factors tending to make K_r different from the laboratory K_1 were noted by McKee and Wolf (1963) to fall into two categories, using K_3 as the basis of comparison:

a. Factors making K_3 positive:

   i. sedimentation

   ii. volatilization of organic acids

   iii. adsorption, as influenced by the area/volume relationship of the stream channel

   iv. flocculation

   v. biological activities of attached growths

b. Factors making K_3 negative:

   i. sludge banks

   ii. channel scour

   iii. longitudinal mixing and short-circuiting.

The need for accurate time of travel data for use of Eq. 29 was emphasized by McKee and Wolf (1963, p. 21).

The values of K_r (base 10) which have been evaluated in stream pollution studies have varied considerably from laboratory values. Courchaine (1963) and Purdy (1966) reported values of 0.8 to 1.1 in stream studies in Michigan. Phelps (1944) plotted values for the Ohio River, relating K_r with the time of travel observed between sampling stations, and illustrated that K_r varied from 0.10 to 0.70, increasing with shorter travel times. Courchaine (1963) observed also that the overall K_r value for combined nitrogenous and carbonaceous BOD was greater than that determined from the carbonaceous demand only.

McKee and Wolf (1963) summarized these concepts of river k rates in noting that seasonal variations could be expected, depending upon the influence of the several factors related to K_3, and also that with this technique, one could learn a great deal about the river and its ability to oxidize or otherwise assimilate a pollutional load.

D. Stream Reaeration and the Oxygen Resource

1. Sources of oxygen

Three sources of oxygen replenishment which serve to resupply the oxygen resource utilized by the biological life contained in the stream environment were listed by Streeter (1924):

1. Dilution water containing relatively high amounts of dissolved oxygen flowing into the stream from local sources or tributaries.

2. Atmospheric reaeration, or the absorption of oxygen directly from the atmosphere.

3. Biological reoxygenation from oxygen producing plants.

These sources of oxygen are of utmost importance in maintaining aerobic conditions in the stream environment. Each will be discussed in the following sections.

2. Solubility of atmospheric oxygen in water

The dissolved oxygen content of dilution water in unpolluted streams depends on the solubility of atmospheric oxygen in the stream water. Various factors affecting the solubility of oxygen and its rate of replenishment have been identified, and were listed by Babbitt and Baumann (1958) as including temperature, atmospheric pressure, turbulence at the surface (as affecting the rate of surface renewal), percentage of oxygen in the atmosphere, area of surface exposed to the atmosphere, salinity, the dissolved solids content of the water, supersaturation caused by oxygen producing plants, and the effect of pollution upon such amounts and rates.

Saturation concentrations of dissolved oxygen (DO) provide the base from which DO deficits are computed in stream pollution studies and determines the driving force which controls the reoxygenation of the water. Controlled laboratory experiments, studying dissolved oxygen uptake in distilled water, have provided a means for evaluating temperature effects as well as the rate of aeration under prescribed reaeration conditions. As summarized by Churchill et al. (1962), the values published in Standard Methods for many years were those calculated by Whipple and Whipple from experimental data of Fox. After Truesdale et al. published their results which varied from the previously published values (8.84 mg/l versus 9.17 mg/l in Standard Methods, at 20 deg C), additional verification was sought by the U.S. Public Health Service, at Harvard University. A careful duplication of techniques used by both previous experimenters was made, with the results indicating no reason to refute the work of Truesdale's group. As explained by Churchill et al. (1962) the third study within the decade was initiated to provide additional confirmation of saturation values because of the need to know true values in stream reaeration and pollution studies.

In the latest research effort, utmost care was used in techniques, equipment, and procedures. Water was deoxygenated by bubbling a stream of gaseous nitrogen through it; thereafter with gentle stirring the water was allowed to absorb oxygen from the atmosphere until equilibrium was reached for the temperature concerned. In a second phase at the same temperature, water was supersaturated with gaseous oxygen and again permitted to reach equilibrium. In each phase, five replicates were used for statistical comparison. Determinations of DO concentrations were made by the Winkler method, using an amperometric endpoint in the final titration. Seven different temperature ranges were used, being approximately 2, 5, 9, 16, 20, 23, and 29 deg C, thus including most of the temperature range encountered in natural waters.

Using multiple regression techniques, the mathematical model given for the variation of saturated DO levels with temperature was derived (Committee on Sanitary Engineering Research, A.S.C.E., 1960; Churchill et al., 1962) as

$$C_s = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3 \quad (32)$$

where

C_s = saturation concentration of DO, mg/1, and

T = temperature in deg C.

At a temperature of 20 deg C the value of C_s is 9.02 mg/l, a value almost equally between the values previously reported (8.84 and 9.17 mg/l). The coefficient of multiple correlation was 0.99980, indicating a great deal of precision in the experimental work. However, recent studies in Iowa have provided some indication that the values for C_s are still in question, and Whipple's results may be the more applicable (Baumann, 1968).

3. Stream reaeration factors

a. Basic concepts The value of reaeration in the stream purification role was recognized early, as indicated by the summary made previously by Theriault (1927). Although many reaeration studies have been made in laboratories, stream reaeration is of major concern in this study.

The results of various studies of atmospheric reaeration of water which were made early in this century have been summarized by various researchers (Streeter and Phelps, 1925; Streeter, 1924; Theriault, 1927; Fair and Geyer, 1954). The rate of reaeration (or reoxygenation) was shown to be directly proportional to the saturation deficit, as experimentally verified using deaerated water samples. The differential rate of reaeration was expressed as

$$\frac{dD}{dt} = - rD \qquad (33)$$

where

D = oxygen deficit, mg/l, at any time,

t = time, in days, and

r = coefficient of reaeration, per day, base e (K_2, base 10).

Using as an initial condition, $D = D_a$ at $t = 0$, the differential equation was integrated to yield

$$D = D_a \exp(-rt) = D_a 10^{-K_2 t} \qquad (34)$$

where

$r = 2.3 K_2$.

In accordance with the Fickian laws of diffusion, the coefficient of reaeration was noted to be a function of water temperature, the area of the air-water interface in relation to volume, surface exposure, depth, and turbulence and mixing effects (Streeter and Phelps, 1925; Fair and Geyer, 1954). Streeter and Phelps (1925) reduced the number of variables to the three considered most important, temperature, stream depth and turbulence, in a study of stream reaeration of the Ohio River. From early work by Black and Phelps and others (Streeter, 1924; Theriault, 1927), the temperature relationship was expressed as

$$\frac{r_T}{r_{20}} = \frac{(K_2)_T}{(K_2)_{20}} = \theta^{T-20} \qquad (35)$$

where

r_T = reaeration coefficient, base e, at any temperature, per day,

r_{20} = reaeration coefficient, base e, at 20 deg C, per day,

$(K_2)_T$, $(K_2)_{20}$ = corresponding coefficients, base 10,

θ = thermal or temperature coefficient for reaeration, and

T = temperature for which r_T, or $(K_2)_{20}$, is desired, deg C.

Various values of θ have been reported (Streeter, 1924; Theriault, 1927; Phelps, 1944; Babbitt and Baumann, 1958; O'Connor and Dobbins, 1958; Committee on Sanitary Engineering Research, American Society of Civil Engineers, 1961). The value of 1.0159 was commonly accepted for many years. Phelps (1944) advocated using a value of 1.047, based upon reanalysis of Ohio River data. After conducting extensive and closely controlled experiments under laboratory conditions, the Committee on Sanitary Engineering Research (1961) reported a value for θ of 1.0241.

b. <u>Relationship of K_2 and stream characteristics</u> The standard value of the coefficient of reaeration, K_2 (base 10), was further related to the depth and velocity of streamflow, the latter parameter representing the effect of turbulence (Streeter and Phelps, 1925). The empirical relationship developed during the Ohio River studies was expressed as

$$K_2 = \frac{CU^n}{H^2} \tag{36}$$

where

K_2 = reaeration coefficient, per day, at 20 deg C, base 10,

U = mean or average velocity of flow, fps,

H = mean depth of flow, feet,

C = constant, and

n = exponent for U, a constant.

Values of C for the Ohio River varied from almost 0 to 131, and values of the exponent n varied from 0.51 to 5.40. Additional relationships were developed to relate n to increases in mean velocity with stage increases, and also to relate C to stream slope and irregularity of channel alignment. In the Ohio River studies, the existence of navigation dams made it necessary to separate the analysis into "dam up" and "dam down" conditions (for movable weir dams), permitting normal flow conditions to be distinguished from more quiescent pool conditions.

Velz (1939) further elaborated on the process of reaeration. The rate of reaeration was determined to be a function of time, depth, and the magnitude of the diffusion coefficient. Additional application of the basic theory of fluid turbulence and related effects was made by O'Connor and Dobbins (1958) for two types of turbulence. Relationships among turbulence parameters, the reaeration coefficient, and the rate of surface renewal were developed for both isotropic and nonisotropic turbulence. For isotropic turbulence, defined as that indicated by a complete lack of correlation of the velocity fluctuation in different directions, the mathematical model derived was

$$K_2 = \frac{127\ (D_L U)^{1/2}}{H^{3/2}} \quad . \tag{37}$$

where

K_2 = reaeration coefficient, base 10, per day,

D_L = coefficient of molecular diffusion of oxygen in water, in square feet per day, and

D_L = 0.00194 sq ft per day at 20 deg C, and

$D_L = 0.00194\ (1.028)^{(T-20)}$ for other temperatures,

U = average stream velocity, fps, and

H = mean depth of flow, feet.

A second mathematical model was developed for nonisotropic turbulence, characterized by a significant correlation between velocity fluctuations and existence of a velocity gradient and shearing stress,

$$K_2 = \frac{480\ D_L^{1/2} S^{1/4}}{H^{5/4}} \tag{38}$$

where

S = slope of the stream channel, ft per ft, and other terms are defined as above.

The relationship between velocity and slope as expressed in the Chezy formula for open channel flow, and the Chezy coefficient, C, were used to distinguish between isotropic and nonisotropic turbulence. In general, if C is greater than 17, the turbulence is considered to be isotropic, and if C is less than 17, the turbulence is considered to be nonisotropic. In a later discussion, it was mentioned that the isotropic model was providing a better fit with experimental data and was suggested for use in all situations (O'Connor, 1967). Krenkel and Orlob (1962) developed similar models based upon both theoretical considerations of oxygen transfer using molecular diffusivity and the two-film theory, and statistical analysis of the experimental laboratory data. However, evaluation under stream conditions was not accomplished. Other methods of evaluation have also been reported (Churchill et al., 1962; Dobbins, 1964; Owens et al., 1964; Langbein and Durum, 1967).

Churchill et al. (1962) performed extensive field tests of reaeration in streams of the Tennessee River valley system, and applied the concepts of mixing and turbulence incorporating all variables in dimensional analysis. The variables included were the reaeration coefficient, velocity, mean depth, energy slope, resistance coefficient, density, dynamic viscosity, surface tension, molecular diffusion of liquid films, and the vertical diffusion coefficient. The results indicated that two variables had the greatest influence upon the reaeration coefficient, velocity and mean depth. The prediction model recommended was

$$K_2 = 5.026\, U^{0.969}\, H^{-1.673} \quad (39)$$

Regression analysis yielded a correlation coefficient of 0.822. They recommended for field application the simple form

$$K_2 = \frac{5\, U}{H^{5/3}} \quad (40)$$

where

K_2 = reaeration coefficient, 20 deg C, base 10, per day,

U = average stream velocity, fps, and

H = average stream depth, feet.

The range of values used in developing the prediction model extended from 1.85 to 5.00 fps for velocity, and from 2.12 to 11.41 ft for average depth.

Typical values of K_2 (base 10) obtained in the early studies of the Ohio River ranged from 0.05 to 3.98, with mean values of 0.21 to 0.24. Values for the Illinois River were reported to vary from 0.14 to 0.68, with a mean value of 0.27. In one turbulent section of the Des Plaines River, a value of 2.6 was reported as a maximum (Streeter, 1924; Streeter and Phelps, 1925). In the Tennessee River studies, values of K_2 ranged from 0.225 to 5.56, with the lower values always being associated with depths of 8 to 11 ft.

Values of K_2 commonly reported in earlier publications (Babbitt and Baumann, 1958) were

Stream type	K_2, 20 deg C
Small ponds and backwater	0.05 to 0.10
Sluggish streams and large lakes	0.10 to 0.15
Large streams of low velocity	0.15 to 0.20
Large streams of normal velocity	0.20 to 0.30
Swift streams	0.30 to 0.50
Rapids and waterfalls	0.50 and greater

The fact that depth plays a greater role than does velocity in causing variations in the reaeration coefficient was substantiated in a recent publication of the U.S. Geological Survey (Langbein and Durum, 1967). The reaeration coefficient was related to velocity and depth, similar to Eqs. 36 and 40, and then compared to discharge and other stream characteristics. The mathematical model expressed in this report was

$$K_2 = \frac{3.3\ U}{H^{1.33}} \tag{41}$$

where

U = mean velocity, fps,

H = mean depth, feet, and

K_2 = reaeration coefficient, 20 deg C, base 10.

Both laboratory and field data were used in this study.

c. Regional estimates of reaeration The regional contrast in values of the reaeration coefficient obtained in field studies of both mountain streams and those in coastal plains showed that for equal discharges, the mountain streams had larger coefficients (Langbein and Durum, 1967). Values of K_2 ranged from 1 to 10 for the mountain streams, and from about 0.09 to 3.5 for the coastal plain streams. Hydraulic data for the Kansas, Missouri, and Mississippi Rivers were used to determine the relative differences in the reaeration coefficients obtained from these streams. Based upon Eq. 41, and using hydraulic data of Leopold and Maddock (1953) the results shown in Table 9 were obtained. Plotted on log-log paper, the regression line as given in the report gave the relationship

$$K_2 = 61.5\ Q^{-0.496} \tag{42}$$

where

Q = stream discharge, cfs, at the average discharge level, and

K_2 = reaeration coefficient, base 10, at average discharge of the stream, for discharges greater than 2,000 cfs.

These data tend to confirm that in larger streams the influence of greater depths overshadows the smaller increase noted in velocity, with the general result being a lower value of the coefficient for increasing stream size. Langbein and Durum (1967) indicated that in general the reaeration coefficient would decrease in the downstream direction at about the 0.43 power of discharge, Q. To further illustrate the relationship of stream hydraulic parameters to the reaeration coefficient, average values for streams in the United States were provided. These are tabulated in Table 10. The values as computed using Eq. 41 show clearly the general influence of stream size on the coefficient of aeration.

Table 9. Relationship of the reaeration coefficient with hydraulic data[a]

Stream	Location	Mean discharge, cfs	Mean velocity, fps	Mean depth, ft	K_2, per day[b]
Kansas	Ogden, Kansas	2,514	1.9	3.8	1.07
	Wamego, Kansas	4,114	1.9	4.1	0.96
	Topeka, Kansas	4,655	2.1	4.6	0.92
	Bonner Springs, Kansas	5,874	1.8	5.9	0.56
	Lecompton, Kansas	7,838	2.3	4.6	1.0
Missouri	Bismarck, North Dakota	20,320	2.9	6.1	0.87
	Pierre, South Dakota	22,080	2.5	9.1	0.44
	St. Joseph, Missouri	35,440	3.6	11.5	0.45
	Kansas City, Missouri	43,710	3.4	11.7	0.42
	Hermann, Missouri	69,170	3.0	14.5	0.28
Mississippi	Alton, Illinois	96,670	3.0	18.6	0.20
	St. Louis, Missouri	166,700	3.8	28.0	0.15
	Memphis, Tennessee	454,900	4.6	51.0	0.073
	Vicksburg, Mississippi	554,600	5.3	40.1	0.11

[a]Source: Langbein and Durum (1967).

[b]Computed using Eq. 41, on basis of 20 deg C, base 10.

Low water variations were also discussed by Langbein and Durum (1967). Values of K_2 at low water varied from 0.13 in pools to 4.1 in the riffle section of the Kansas River at Bonner Springs, Kansas. For mean flow (average discharge conditions) the variation was less, from 0.23 to 2.2, and at bankfull stages the riffles and pools coalesced ("drowned" out), giving a value of 0.43. The general capability of the total stream system in the United States to assimilate organic wastes, as measured by the reaeration capability, was also estimated in this report.

Table 10. Variation of the reaeration coefficient with size of stream[a]

Stream order	Average discharge, cfs	Average depth, ft	Average velocity, fps	Computed coefficient, K_2, per day
1	0.6	–	–	–
2	2.8	–	–	–
3	14	0.55	1.2	9.3
4	65	0.95	1.6	5.5
5	310	1.8	1.8	2.6
6	1,500	2.7	2.0	1.8
7	7,000	5.	2.5	1.0
8	33,000	12.	3.0	0.37
9	160,000	25.	4.0	0.19
10	700,000	45.	5.0	0.10

[a]Source: Langbein and Durum (1967).

4. Effect of algae upon the oxygen resource

a. Fundamental principles Both microscopic plants and animals are of interest and play a role in stream purification. McKinney (1962) identified these as the bacteria, fungi, algae, protozoa and higher animals, with the first three being of the plant kingdom. Because algae can use light energy and evolve oxygen in the process of photosynthesis, they must be included in the sources of oxygen for stream reaeration. Of concern in this review are the methods of measuring oxygen production by algae and relating this production to potential nutrient loads.

Klein (1962, p. 318) considered the benthic algae (those attached to the stream bed, bank or other water weeds) as the primary form existing in a stable stream environment. The algae belonging to the planktonic community (the algae living in suspension in the flowing water) were noted as being derived basically from the benthic community. Churchill et al. (1962) found in a study of benthic plant effects on stream reaeration that the photosynthetic and respiration effects of the plankton were negligible. The streams involved were tributaries of the Tennessee River, with 5-day BOD values being less than 1.5 mg/l. The combined BOD and planktonic effect was less than 5% of the variation observed for either benthic respiration or photosynthesis. This basic difference between the two types, with the benthic algae being fixed at the boundary and the planktonic algae being in transit in the flowing water, may be of importance in developing mathematical models of stream behavior.

The growth and productivity characteristics of algae have been described in various references (Smith, 1950; Fair and Geyer, 1954; Klein, 1962; McKinney, 1962; McKee and Wolf, 1963; Ruttner, 1963). Algae are classified as autotrophic organisms, using inorganic compounds for their metabolic requirements in forming cell protoplasm. Carbon, hydrogen, nitrogen and phosphorus are recognized as the most important constituents of living cells. For algae, carbon dioxide serves as the source of carbon, nitrogen can be used in the form of ammonia, nitrite, or nitrate. Phosphorus is used in the orthophosphate state. Trace elements also are required. As discussed previously in the historical review, nitrogen and phosphorus have been identified as the key nutrients leading to excessive algal growth and resultant blooms. Ruttner (1963) discussed the ability of many of these microorganisms including the blue-green algae and others to fix atmospheric nitrogen (which is soluble in water in a manner similar to oxygen). As a result, phosphorus control is becoming recognized as a primary factor in water pollution control programs (Levin, 1967).

In the water environment, two fundamental environmental principles have been recognized (Ruttner, 1963): the law of the minimum and the principle of limiting factors. The first states that productivity is limited by the nutrient present in the least amount at any given time. According to the second, other factors can be influencing the life and growth process, in addition to specific nutrients (such as temperature), thus limiting productivity even if other nutrients are in excess. Two specific relationships observed and reported by Ruttner (1963) may also have a bearing on the nutrient problem. The algae have the ability to rapidly withdraw and store large quantities of these limiting nutrients from solution, including phosphorus. Experiments have shown also that following this initial storage phase, even where the nutrient source has been replaced by completely nutrient-free water, the algae continue to grow actively for periods up to a month. Therefore, nutrient uptake (adsorption) and algal productivity may be separated by a time lag.

Algae produce oxygen during the daylight hours through the process of photosynthesis, but require at the same time a certain level of oxygen in the respiration phase. However, the respiration phase is most evident in the nighttime when photosynthesis ceases. McKinney (1962) noted that some algae need oxygen for metabolic processes similar to bacterial requirements for oxidation purposes, and others need oxygen in the process of endogenous metabolism. To quantify the two phases, two terms have been introduced. These are P, for production of oxygen, and R, for the respiration requirement. The quantity (P - R) represents the net effect of the photosynthesis-respiration process, being a positive quantity when photosynthesis exceeds respiration, and negative when the latter predominates. The P/R ratio is a second parameter which has been used in experimental studies (Churchill et al., 1962). In discussing production biology, Ruttner (1963) listed the two bases of measurement for P and R, the first being the unit surface area of the water environment and the second being a unit volume of water. Although the two dimensional bases are related by the depth dimension, transparency and the variation of light intensity with depth are additional factors to be considered. On a volumetric basis, values of (P - R) can be expressed in terms of mg/l per hour or per day. On the basis of surface area, oxygen productivity is usually expressed in grams per square meter per day, or in English units, pounds per acre per day. Because photosynthesis can cause temporary supersaturation of dissolved oxygen, results can also be expressed in terms of percent saturation, insofar as increases in the stream oxygen resource are concerned.

Experimental methods of evaluating P and R have included the dark and light bottle incubation techniques described by Churchill et al. (1962). In-place samples are obtained, a portion is used for initial DO determination, and the remainder is placed in duplicate bottles. One bottle is darkened or covered; the dark and light bottles are then incubated at the depth sampled, making use of rafts in the natural stream environment. Laboratory experiments under controlled conditions, using an artificial light source, have also been used to study P/R effects. After the desired period of incubation, the submerged samples are withdrawn and the DO content determined. The gain of oxygen content in the light bottle represents the net effect of photosynthesis; the loss of oxygen in the dark bottle represents both respiration and all organic oxidation requirements. If the organic oxidation requirement is negligible, this method can provide accurate P/R relationships directly. Camp (1965) noted that the difference in final DO concentrations is the gross photosynthetic value.

b. Quantitative observations The net contribution of photosynthetic oxygen production and the respiration requirement have been evaluated in streams by determining for short reaches all other oxidation and reaeration effects and solving for the (P - R) value. O'Connell and Thomas (1965) improved upon previous efforts in this direction, based upon Odum's (1956) development of an upstream-downstream method of diurnal DO analysis for estimating algal productivity. Deoxygenation from both carbonaceous and nitrogenous organic matter was included in the more recent work. Atmospheric reaeration was a source of oxygen replenishment in addition to photosynthesis. The differential equation used in the "finite time difference" analysis is

$$\frac{dD}{dt} = kL - rD - (P - R) \qquad (43)$$

where

D = oxygen deficit, mg/l, as defined also in Eq. 33,

L = oxygen demand of carbonaceous and nitrogenous organic matter (although evaluated separately in practice), mg/l,

(P - R) = net effect of algae on the oxygen supply, photosynthesis minus respiration, mg/l per unit of time,

k and r = coefficients of deoxygenation and reaeration, as defined previously, per unit of time (either per day or per hour in this technique), and

t = time, days or hours.

This is a form of the differential equation of the Streeter-Phelps (1925) formulation of the oxygen sag curve, with the algal contribution added.

Similar techniques were used by Churchill et al. (1962) in the study of reaeration in tributaries of the Tennessee River. In addition, laboratory studies of river bed samples were made to determine P/R ratios for various light intensities and temperature conditions. These studies showed that <u>temperature did not affect the P/R ratios</u> obtained for a wide range of light intensities, extending from 400 to 1000 foot-candles. Oswald and Gotaas (1957) indicated that this range of light intensities would be experienced in the middle latitudes. P/R ratios varied from about 1 to more than 5 at the highest light intensities in the laboratory studies, and field conditions resulted in P/R ratios up to 3.5 and 4.0, in the Tennessee River basin studies. Typical values for P and R were 0.68 to 0.72 and 0.15 to 0.18 mg/l per hour, respectively, with the value of P being the maximum during the day.

O'Connell and Thomas (1965) made studies of the Truckee River downstream of the Reno water pollution control plant, which utilized the trickling filter for secondary treatment. A daytime zone of maximum oxygen productivity and minimum nighttime oxygen levels from respiration was identified, extending about 5 mi downstream of the plant outfall. Respiration varied from 0.8 to 0.9 mg/l per hour during the nighttime respiration phase, to a daytime maximum value for (P - R) of about 1.4 mg/l per hour [or P = (P - R) + R = 1.4 + 0.8 = 2.2 mg/l per hour gross photosynthesis]. In this assimilative reach, it was noted that the total nitrogen (as N) and orthophosphate (as PO_4) increased from 0.3 and 0.08 mg/l, respectively, upstream of the outfall, to 1.2 and 1.8 mg/l respectively, immediately downstream of the outfall. This increase in nutrients resulted in greater diurnal variations in dissolved oxygen, from the upstream range of 6.5 to 9.0 to the range experienced in the downstream assimilative reach of 3.5 to 13.5 mg/l.

The diurnal variations of (P - R) approximated a sinusoidal curve, peaking at 1300 to 1400 hr and with a minimum at about midnight to 0200, which for the season (July) gave zero values of (P - R) at about 1/2 hr after sunrise and 1-1/2 hr before sunset. This diurnal effect is illustrated in Fig. 2. In this area of peak algal activity, the oxygen contributed by photosynthesis was calculated on a surface area basis as 126 lb/acre/day, and respiration was evaluated as 115 lb/acre/day, indicating that daily values of contribution and demand are about equal in magnitude, with a small net oxygen contribution. These surface rates of oxygen production and respiration are obtained by (1) computing the base level of respiration for a 24-hr period and integrating the area under the diurnal photosynthesis production curve as illustrated in Fig. 2, and

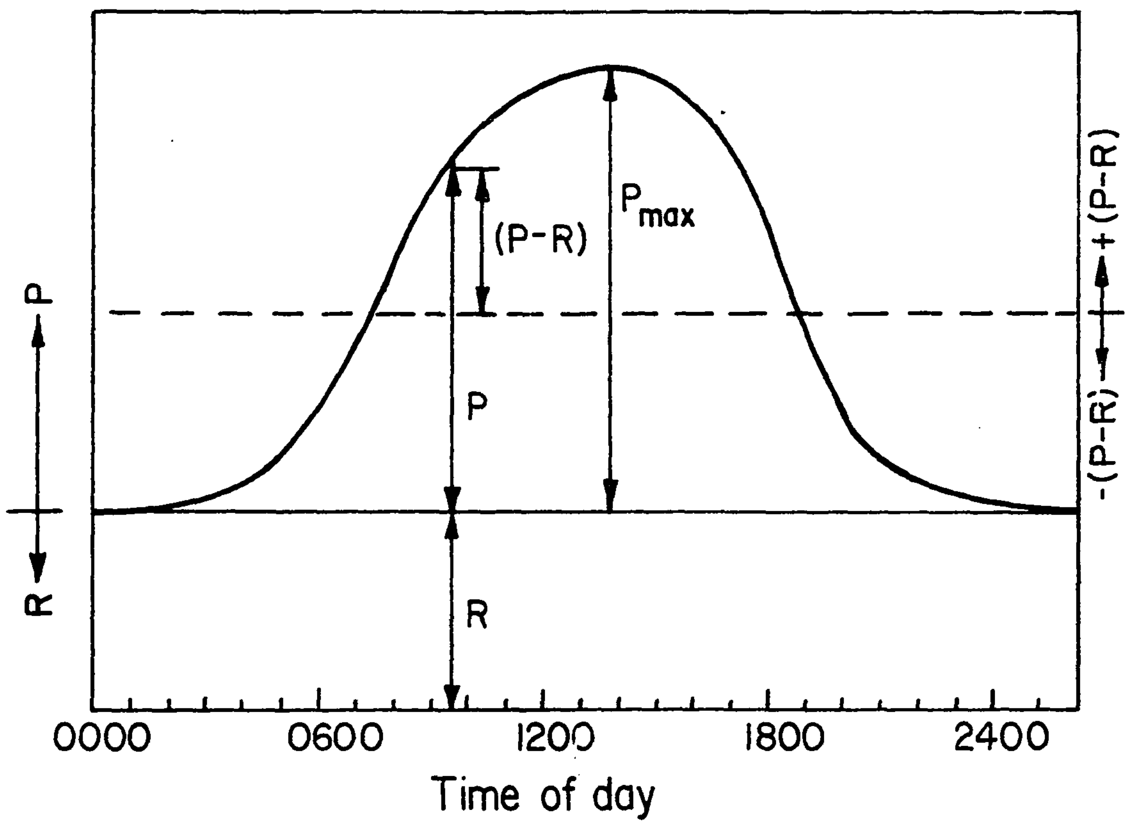

Fig. 2. The diurnal relationship of photosynthesis and respiration phases of algal effects upon the dissolved oxygen resource of the stream (after O'Connell and Thomas, 1965).

(2) determining the volume and surface area involved in the reach of stream being evaluated.

Camp (1965) made similar analysis of the algae contribution in a study of the Merrimack River in New England. The net rate of photosynthesis (P - R) was determined on an average daily basis, rather than evaluating a daily maximum. The average daily contributions of (P - R) varied from 0.55 to 2.9 mg/l per day.

Other researchers have also observed the increase in algal activity downstream of water pollution control plants. Blain and McDonnell (1967) reported on reaeration measurements made on a small stream reach in Pennsylvania downstream of a plant outfall. A reach was observed that contained a maximum daytime DO value (reflecting maximum algal activity) and a corresponding minimum nighttime DO value. DO values varied from a daytime maximum value of 14 to 16 mg/l and a nighttime minimum value of 2 to 3 mg/l. Water temperatures ranged from 20 deg C in the daytime to 14 deg C at night, showing that substantial algal activity (in terms of high values of daytime DO and low nighttime values) can exist at moderate water temperatures. The range of DO upstream of the discharge point was from 9 mg/l at night to 11 mg/l in the daytime. Phosphorus levels, as mg PO_4/l, varied from 0.04 to 0.07 upstream to 2.3 to 3.5 mg/l downstream, indicating a substantial increase in nutrients. The field evaluation of the reaeration coefficient gave values of 2 to 4 (K_2, 20 deg C), with the stream having a drainage area of 108 sq mi, and with the discharge varying from 20 to 35 cfs at the time of the field studies. Schroepfer (1942) reported on similar nutrient problems and algal productivity.

Bartsch (1958) reported values of oxygen production by algae for both the Ohio River and for a waste stabilization pond in South Dakota. Values were, for P and R and the P/R ratio:

Location	Photosynthesis, P, #/ac/day	Respiration, R, #/ac/day	P/R
Ohio River	57	45	1.3
South Dakota pond	183	130	1.4

Bartsch concluded from a general review of the oxygen production cycle that if the P/R ratios exceeded about 1.5, then high daytime oxygen production by dense algal populations would be accompanied by rapid respiratory use persisting around the clock. Nocturnal depression of dissolved oxygen would be mild to severe. In reaches of the Ohio River where algal populations were high, respiration rates averaged 0.3 to 0.5 mg/l/hr and peak daily photosynthesis reached 1.4 mg/l/hr in the top 1 ft of depth.

Additional algal relationships with nutrient loads can be found in literature directed towards the use of oxidation ponds for organic waste treatment (Oswald and Gotaas, 1957; Fitzgerald and Rohlich, 1958; Loehr and Stephenson, 1965). A definite increase in the algal concentration and the dry weight of algal cells produced with increasing BOD concentrations was reported (Oswald and Gotaas, 1957). The dry weight of algal cells produced doubled as the BOD was increased from 0 to 50 mg/l, although the rate of cell production decreased as BOD concentrations were increased. Loehr and Stephenson (1965) studied an oxidation pond being used for tertiary treatment following a trickling filter process. They observed dissolved oxygen levels of 20 to 25 mg/l with the influent level of phosphates (after mixing) in the range of 7 to 8 mg/l as PO_4, high nitrogen levels, and pond temperatures of 25 to 29 deg C (June to August). Frequently, DO supersaturation continued through the nighttime hours. Oswald and Golueke (1966) made laboratory studies of the "algal growth potential" (AGP), and in terms of the packed volume of algal biomass showed that as the concentration of PO_4 was increased from 0.01 mg/l to 1.0 mg/l, the productivity increased about 150 to 200%. Stream water from areas having irrigation return flow was used in the study.

These results indicate that algal effects upon the oxygen resource may be measurable and need to be included in studies of stream behavior. In a general sense, the effect of nutrient levels in increasing the maximum (P - R) values observed in streams may be approximated. The concept of (P - R) can be expressed in quantitative terms and included in mathematical models of the dissolved oxygen resource, thus permitting algal effects to be evaluated. The relationship between maximum (P - R) values and nutrient levels appears sufficiently well established to use it as a means of estimating oxygen production.

E. Mathematical Models of Stream Behavior

1. General

The response of the stream environment to the effect of specific pollutants or organisms having a quantitative influence on water quality has been evaluated in the previous section. For conservative substances which are not involved in biological life processes, several of the mathematical models apply as outlined. However, combined effects from more than one source must be considered and included in the fundamental differential equation form. Two major influences have received the most attention in regard to the stream environment. The first is the combined effect of deoxygenation and reaeration, considering the several sources of each. The second, related influence is the decay through oxidation of the organic substances, and their resultant spatial and temporal distribution in the stream environment. As noted in the historical section, maintenance of desired fresh water biota and clean stream conditions has depended fundamentally on having an adequate supply of oxygen. Therefore, models of the dissolved oxygen resource have received the major emphasis in stream water quality studies.

2. The original oxygen balance formulation of Streeter and Phelps

The oxygen balance in a stream was of primary interest to Streeter and Phelps (1925), who were among the early researchers to recognize that the capacity of a stream to receive and oxidize organic wastes depended on the oxygen resource. The characteristic "oxygen sag" curve was developed by combining the two opposing reactions first recognized, deoxygenation by carbonaceous organic wastes and stream reaeration from the atmosphere. The first-order reactions given in Eqs. 11 and 33 were combined to give for the rate of change of the DO deficit,

$$\frac{dD}{dt} = kL - rD \tag{44}$$

The initial condition for the assumptions of steady, uniform flow in the stream between waste discharge points or sampling stations was $D = D_a$ at $t = 0$. This differential equation of the second order was integrated to yield

$$D = \frac{kL_a}{r - k} [\exp(- kt) - \exp(- rt)] + D_a \exp(- rt) \qquad (45)$$

or, to base 10,

$$D = \frac{K_1 L_a}{K_2 - K_1} (10^{-K_1 t} - 10^{-K_2 t}) + D_a\ 10^{-K_2 t} \qquad (46)$$

where

D = dissolved oxygen deficit below saturation, mg/l,

D_a = initial dissolved oxygen saturation deficit at initial point of reference at $t = 0$, mg/l,

L_a = initial carbonaceous oxygen demand of the organic matter, mg/l (so-called first-stage BOD),

$k = 2.3\ K_1$ = deoxygenation coefficient, per day,

$r = 2.3\ K_2$ = coefficient of reaeration, per day, and

t = elapsed time, from point of reference, in days.

This model does not apply if $r = k$. It was used in the original studies of pollution of the Ohio River to illustrate the reduction of BOD and to evaluate the rate of reaeration, r. The value of K_1 was determined to be approximately 0.10 (20 deg C), and Eq. 46 was used to determine K_2, using a trial and error procedure (Streeter and Phelps, 1925; Streeter, 1936).

The critical deficit, D_c, was obtained by differentiating Eq. 45 for a minimum, $dD/dt = 0$ at the elapsed time $t = t_c$. This yielded

$$t_c = \frac{1}{r - k} \ln \left\{ \frac{r}{k} [1 - (\frac{r}{k} - 1) \frac{D_a}{L_a}] \right\} \tag{47}$$

and

$$D_c = \frac{k}{r} L_a \exp(- kt_c) \tag{48}$$

The reduction in carbonaceous oxygen demand was assumed to follow that given by Eq. 12. The characteristic oxygen-sag curve is illustrated in Fig. 3, which shows the spoon-shaped curve of oxygen depletion and recovery.

For the case where $r = k$, the appropriate solutions were determined (Thomas, 1948; Fair and Geyer, 1954) to be

$$D = (ktL_a + D_a) \exp(- kt) \tag{49}$$

$$t_c = \frac{1}{k} (1 - \frac{D_a}{L_a}) \tag{50}$$

$$D_c = (kt_c L_a + D_a) \exp(- kt_c) \tag{51}$$

3. <u>Additional concepts of boundary conditions</u>

It was recognized, in using the mathematical models developed in the previous section, that maximum stress conditions could be outlined for a given set of conditions (Fair, 1939; Phelps, 1944; Thomas, 1948). If septic, anaerobic stream conditions are to be avoided, the maximum permissible magnitude of the critical oxygen deficit, D_c, is the saturation value of dissolved oxygen, C_s, which would exist at the temperature of the combined effluent and stream discharge (Eq. 32, as corrected for barometric pressure and dissolved solids), or $D_c = C_s$. Critical values of DO needed for maintenance of aquatic life which would

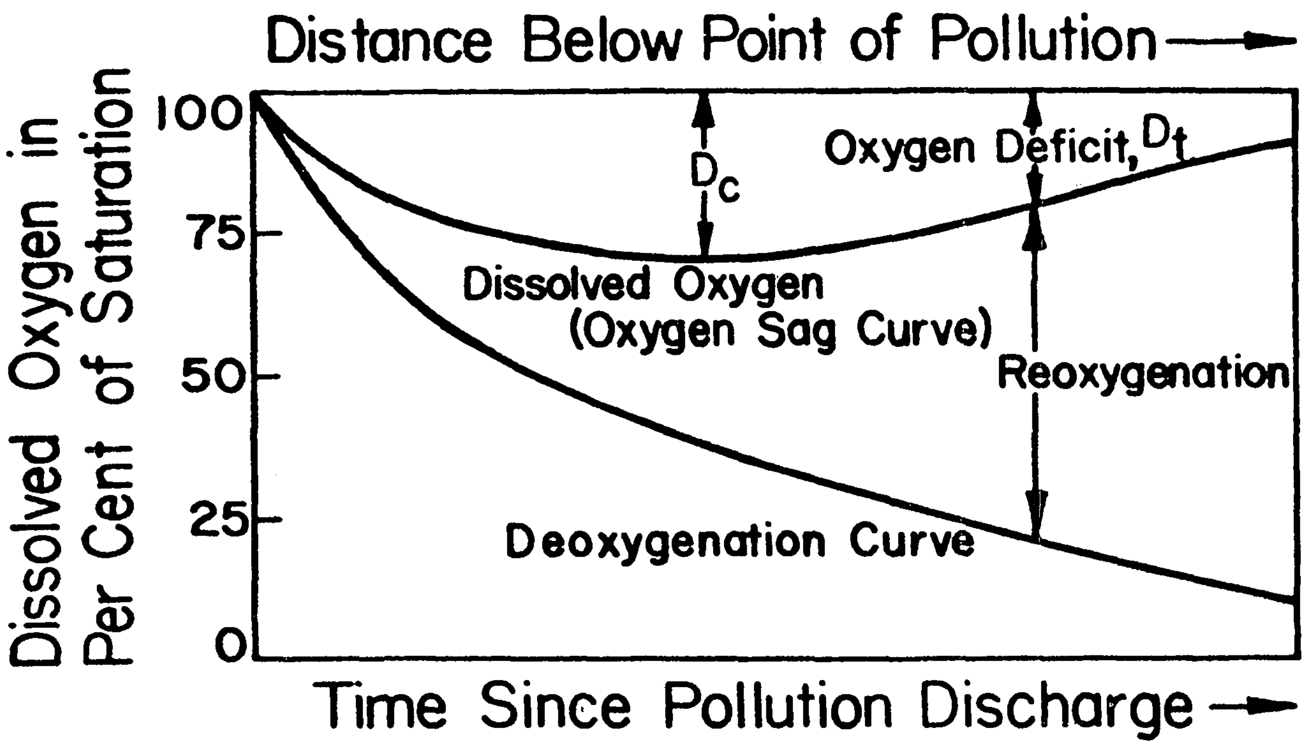

Fig. 3. Characteristics of the oxygen sag curve.

reduce this maximum permissible reduction have been discussed previously. However, this maximum reduction made possible additional amplification and further simplification of the original dissolved oxygen mathematical model.

It was observed, for given values of k, r, and D_c ($D_c \leq C_s$) that the initial deficit D_a established two boundary values for the maximum loading that could be imposed on a receiving stream. The upper limit was associated with a zero initial deficit (complete saturation, $D_a = 0$), and a lower limit associated with an initial deficit equal to the desired critical deficit ($D_a = D_c$). In addition, the ratio of the coefficients of reaeration and deoxygenation was introduced and labeled as the coefficient of "self-purification" for streams, or

$$f = \frac{r}{k} = \frac{K_2}{K_1} \tag{52}$$

Combining these boundary conditions with Eqs. 44 through 51, the two limits were evaluated. The upper limit of maximum loading was determined to be

$$\frac{L'_a}{D_c} = f^{\left(\frac{f}{f-1}\right)} = f \exp(kt'_c) \tag{53}$$

and

$$t'_c = \frac{1}{k(f - 1)} \ln(f) \tag{54}$$

where

L'_a = maximum initial loading in the stream for $D_a = 0$,

t'_c = critical time for the upper limit criteria, to the point of minimum dissolved oxygen, where D_c occurs, and f = coefficient of self purification.

The lower limit was determined to be, for the condition $D_a = D_c = C_s$,

$$\frac{L''_a}{D_c} = f \qquad (55)$$

$$t''_c = 0 \qquad (56)$$

For the special condition r = k, or f = 1,

$$L'_a = \frac{1}{k} \qquad (57)$$

and

$$t'_c = e = 2.718... \qquad (58)$$

In addition, the ratio of the limits was determined to be

$$\frac{L'_a}{L''_a} = \exp(kt'_c) = f^{\frac{1}{f-1}} \qquad (59)$$

These determinations showed that the allowable loading limits were simple functions of the coefficient of self-purification. Similar equations and summary values were computed for the inflection point, or point of maximum rate of recovery of the oxygen sag curve following the minimum point position, as illustrated in Fig. 3. The actual dissolved oxygen concentration in the stream, once the deficit is computed, is obtained as

$$C = C_s - D \qquad (60)$$

where

C = actual dissolved oxygen concentration in the stream, mg/l,

C_s = saturation dissolved oxygen concentration for the given conditions of temperature, etc., and

D = computed oxygen deficit, mg/l.

The permissible concentrations of organic matter in the effluent could then be determined from these boundary conditions using Eq. 1. Values of the coefficient of self-purification, f, were given by Fair and Geyer (1954) as

Nature of receiving water	Value of f, 20 deg C
Small ponds and backwaters	0.5 to 1.0
Sluggish streams and large lakes or impoundments	1.0 to 1.5
Large streams of low velocity	1.5 to 2.0
Large streams of moderate velocity	2.0 to 3.0
Swift streams	3.0 to 5.0
Rapids and waterfalls	Above 5.0

Temperature corrections can be introduced in both k and r (Eqs. 14 and 35) and values of f computed for any temperature, T.

4. Additional effect of the bank load contribution

As developed in Eqs. 23 through 27, the effect of uniformly distributed contributions of pollution or dilution along the stream between two stations can be included in mathematical models of the dissolved oxygen resource. Streeter and Phelps (1925), who originated the concept, included it in the differential equation for the oxygen deficit. To simplify writing the terms repeatedly, in this discussion let

$$B = \frac{[p(dt)]}{1 - \exp[- k(dt)]} = \frac{p}{k} = B_L(24\ U)/k \qquad (61)$$

where it is assumed, in the third expression, that dt = 1 and k is small [or k(dt) is small] and for the fourth expression, accredited to Worley et al. (1965) that

B = daily bank load contribution, or total bank load contribution in time dt, in mg/l or pounds,

B_L = bank load, in mg/l per mile (or converted from pounds per mile),

U = average stream velocity, mph, with 24 U being in miles per day,

k = coefficient of deoxygenation, per day,

p = uniform contribution of BOD, mg/l per day (or pounds per day), and

dt = small increment of time, in days.

The differential equation for the DO deficit then becomes

$$\frac{dD}{dt} = k(L + L_t) - rD = k\left\{L_a \exp(- kt) + B[1 - \exp(- kt)]\right\} - rD \qquad (62)$$

Using the initial condition, $D = D_a$ at $t = 0$, integration yielded the result

$$D = D_a \exp(- rt) + \frac{kL_a}{r - k}[\exp(- kt) - \exp(- rt)] + \frac{k}{r} B[1 - \exp(- rt)] - \frac{k}{r - k} B[\exp(- kt) - \exp(- rt)] \qquad (63)$$

where the last two terms represent the additional influence of the bank load upon the dissolved oxygen resource. Camp (1965) included the concept of p in a mathematical model for dissolved oxygen in studies of the Merrimack River, but considered it to represent the addition of BOD to the overlying waters from the bottom deposits in mg/l per day.

The decay rate for the carbonaceous organic matter is given by Eq. 25, or in terms of B,

$$
\begin{aligned}
L &= L_a \exp(-kt) + B[1 - \exp(-kt)] \\
&= (L_a - B)\exp(-kt) + B \qquad (64)
\end{aligned}
$$

which indicates a constant level of organic matter (and constant BOD values) as the time, t, approaches infinity.

5. Additional effect of sludge loads

For particulate matter in the form of settleable solids, the techniques of Streeter (1935a) and Velz (1958) can be applied, as noted in references used in developing Eq. 28. This involves separation of effluent loads into the dissolved and colloidal fraction and the settleable solids fraction. The truckload method of conveying these organic loads in the downstream direction, mathematically speaking, can then be used in conjunction with step calculations for BOD reduction and reaeration amounts. As noted, with secondary treatment and tertiary methods coming into play, high levels of settleable solids probably will not be experienced in the magnitude of previous years, and this method may not be as useful in future studies.

Worley et al. (1965) introduced a revised concept of sludge deposits in a mathematical model for DO. The term S_L for a characteristic sludge load was defined as the oxygen demand imposed by the benthal deposits on the stream bottom. This definition implies a uniform demand along the full length of the stream as a constant, unchanging quantity, and can be considered the opposite of the algal contribution (P - R) discussed in a preceding section. It differs from the uniform contribution, B or B_L, in that a steady-state condition has been achieved and a continuous demand is exerted in terms of mg/l per unit time or distance. As adopted by Worley et al. (1965), S_L is in units of mg/l per mile (or converted to pounds per mile), and the quantity ($24\ S_L\ U$) represents the oxygen demand in mg/l per day, U being in fps. The differential equation for the DO deficit then becomes, including the bank load

$$\frac{dD}{dt} = k(L + L_t + 24\ S_L\ U) - rD$$
$$= k\left\{L_a \exp(-\ kt) + \frac{24}{k} B_L\ U[1 - \exp(-\ kt)] + 24\ S_L\ U\right\} - rD \tag{65}$$

where all terms have been defined previously.

Integration, evaluation of constants for the initial condition $D = D_a$ at $t = 0$, and collecting terms provided the mathematical model used in studies of the Willamette River basin:

$$D = D_a \exp(-rt) + \frac{(kL_a)}{r - k} [\exp(-kt) - \exp(-rt)]$$
$$+ \frac{24 B_L U}{r(r - k)} \left\{ r[1 - \exp(-kt)] + k[1 - \exp(-rt)] \right\}$$
$$+ \frac{24 S_L U}{r} [1 - \exp(-rt)] \qquad (66)$$

The last term represents the additional oxygen demand exerted by the so-called continuous blanket of benthal deposits. Examination of Eqs. 45 and 63 in comparison to Eq. 66 illustrates the additive effect (linear superposition) of these additional demands.

6. Additional effect of algae

O'Connell and Thomas (1965) included the term (P - R) in the differential equation for the DO deficit. The term was treated as a constant term, although the possibility of variations spatially and temporally was recognized. By using the resulting equation in short intervals of flow time in a finite time difference method, it was assumed that application could be made without introducing excessive error. No consideration was given to sludge deposits or a bank load, and the integrated form of the differential equation was

$$D = D_a \exp(-rt) + \frac{kL_a}{r - k} [\exp(-kt) - \exp(-rt)]$$
$$- \frac{(P - R)}{r} [1 - \exp(-rt)] \qquad (67)$$

Additional treatment of algal productivity and respiration was made by O'Connor (1967). Respiration was included as a volumetric rate, R, and the gross photosynthetic rate was assumed to vary as the solar intensity during the day and to be zero at night. The relationship was defined by a periodic function

$$P_t = P_{max} \sin \frac{t}{p} \pi, \qquad 0 \leq t \leq p \tag{68a}$$

$$P_t = 0 \qquad (1 - p) \leq t \leq 1 \text{ day} \tag{68b}$$

where

P_t = photosynthetic oxygen contribution at any time t, in mg/l per day,

P_{max} = maximum contribution or amplitude of the function, mg/l per day,

p = period for the sine function, assumed as 12 hr normally, and

t = elapsed time, in days.

For an assumed period of 12 hr for the half wave sine function, Eq. 68 was simplified through use of a Fourier series (Wylie, 1960, p. 249), using the first three terms as an approximation:

$$P_t = P_{max} \left(\frac{1}{\pi} + \frac{1}{2} \sin \frac{t}{p} \pi - \frac{2}{3\pi} \cos 2\pi \frac{t}{p}\right) \tag{69}$$

The integrated expression for this mathematical model will be discussed in a later section devoted to the combined effect of all oxygen demands and contributions (sinks and sources).

7. <u>Additional effect of nitrogenous oxygen demand</u>

As noted in the section devoted to nitrogenous oxidation, O'Connell and Thomas included this additional demand using a first-order reaction illustrated by Eq. 22. The FWPCA has included the nitrogenous oxygen demand in mathematical models used in pollution control studies and in determining the amount of dilution water needed in reservoir storage analysis (Grounds, 1967). O'Connor (1967) also adopted the first-order reaction with which to represent the nitrification uptake of oxygen. The differential equation for both carbonaceous and nitrification demands, including the oxygen demand of benthal deposits, then includes the following terms:

$$\frac{dD}{dt} = kL + nN + AS' - rD \qquad (70)$$

where D, t, k, r and L have been defined previously, and

n = deoxygenation coefficient for nitrification, per day,

N = amount of nitrogenous oxygen demand remaining at any time, t, in mg/l,

S' = sludge constant for benthal demand (not defined or explained further), and

A = constant equal to 119.9/Q, with Q being the stream discharge, in cfs.

Integration gave the following result, in terms of base e, and with the initial conditions $L = L_a$ and $N = 4.57\ N_a$ at $t = 0$ where N_a represents the organic nitrogen and ammonia concentrations, in mg/l N-nitrogen:

$$D = D_a \exp(-rt) + \frac{kL_a}{r-k}[\exp(-kt) - \exp(-rt)] + \frac{n(4.57\ N_a)}{r-n}[\exp(-nt) - \exp(-rt)] + \frac{AS}{k}[1 - \exp(-rt)] \qquad (71)$$

This mathematical model indicates that the nitrogenous oxygen demand yields a result similar in form to the carbonaceous fraction, as could be expected. The time lag, a, of Eq. 22 was assumed to be negligible.

8. Introduction of river "k's" into the analysis

All of the mathematical models which have been summarized thus far have used a deoxygenation coefficient given as k (or K_1, base 10). In some analyses, the low rates of k used appear to imply that bottle k's have been used. In other studies, the river k was evaluated separately and then included in the DO analysis. Thomas (1948) recognized the difference in laboratory and river values of the deoxygenation coefficient, as illustrated in Eqs. 29 to 31. Thomas, to correct for this phenomena in the oxygen-sag model, assumed that the deoxygenation rate, dD/dt, due to the oxidation of carbonaceous organic material in the flowing water was only a proportion of the overall measured rate. He postulated that the correct proportion to use was k/k_r, or K_1/K_r for base 10. The differential equation for oxygen balance then became, for carbonaceous oxygen demand only

$$\frac{dD}{dt} = \frac{k}{k_r}(k_r L_a)\exp(-k_r t) - rD$$

$$= kL_a \exp(-k_r t) - rD \tag{72}$$

where

$k_r = 2.3\ K_r$, base 10, and other terms are as defined previously.

Using the same initial condition as in Eqs. 44 to 46 ($D = D_a$ at $t = 0$), the integrated form of this revised model becomes

$$D = \frac{kL_a}{r - k_r}\left[\exp(-k_r t) - \exp(-rt)\right] + D_a \exp(-rt) \qquad (73a)$$

or in base 10 terms,

$$D = \frac{K_1 L_a}{K_2 - K_r}\left(10^{-K_r t} - 10^{-K_2 t}\right) + D_a 10^{-K_2 t} \qquad (73b)$$

In addition, Eq. 31 can be used ($K_r = K_1 + K_3$) and additional evaluation of river effects can be made. Dobbins (1964) and Camp (1965) used this approach in developing mathematical models for river behavior.

F. A Mathematical Model Including All Effects

1. Combined effect of all influences

A review of the many mathematical models which have been proposed or actually used in stream studies has shown that no one model has included all of the responses considered possible. Because certain responses have been considered negligible, or simplifications were needed because of lack of data, only the most important of the several responses have been included in field studies of the stream environment.

The total response of the stream environment as expressed in a detailed mathematical model should reflect the combined influence of the various sources and sinks (reaeration and deoxygenation), as given in the equations presented in the previous section. This universal model would include the effects of initial DO deficit, carbonaceous oxygen demand, nitrogenous oxygen demand, uniform contribution along the stream of organic matter, atmospheric reaeration, and photosynthesis. The effect of concentrated sludge deposits, requiring the truckload method of analysis, is not included in this version because of present-day secondary treatment requirements and related stream standards. The following mathematical model for the dissolved oxygen deficit, as combined from previous equations, is obtained:

$$D = D_a \exp(-rt) \tag{74a}$$

$$= \frac{kL_a}{r-k}[\exp(-kt) - \exp(-rt)] \tag{74b}$$

$$+ \frac{4.57\ nN_a}{r-n}[\exp(-nt) - \exp(-rt)] \tag{74c}$$

$$+ \frac{k}{r}B[1 - \exp(-rt)] - \frac{k}{r-k}B[\exp(-kt) - \exp(-rt)] \tag{74d}$$

$$+ \frac{S}{r}[1 - \exp(-rt)] \tag{74e}$$

$$- \frac{(P-R)}{r}[1 - \exp(-rt)] \tag{74f}$$

where all terms have been defined previously except

S = oxygen demand of bottom benthal deposits, as given by Worley and Towne (1965) and equals 24 $S_L U$, in mg/l per day.

Equation 74a is the exhaustion of the original deficit, common to all of the mathematical models. Equation 74b is the net temporal rate of deoxygenation by the carbonaceous organic matter, and Eq. 74c is for the nitrogenous demand, assuming complete utilization by the nitrifying bacteria. Equation 74d is associated with the uniform contribution of organic matter along the stream, and $B = B_L(24\ U)/k$ of Worley et al. (1965), as shown in Eqs. 61 through 64. Equation 74e is the sludge blanket demand as outlined by Worley et al., and explained above. Equation 74f is the net effect of photosynthesis expressed as a uniform contribution temporally unless short increments of time are used (Dobbins, 1964; O'Connell and Thomas, 1965; Camp, 1965).

2. Additional relationships

The mathematical model for reduction of the initial organic loading in the stream, which is associated with the terms in Eq. 74 is

$$L = L_a \exp(-kt) + 4.57 N_a \exp(-nt) + B[1 - \exp(-kt)] \quad (75)$$

The mathematical model expressed in Eq. 74 is not valid when $r = k = n$. This fact is seldom mentioned in the literature when water quality mathematical models based on first-order reactions are presented. Equations 49 through 51 indicate the additional mathematical treatment required for these special conditions, for the original Streeter-Phelps formulation. The combined model does not reflect the river deoxygenation coefficient, k_r (base e), as being separate from the laboratory value, but such variations can be included by subscripting the value of k in the denominator and in the exponential terms. However, if this influence is included for the carbonaceous demand, it can be hypothesized that a similar development should be made for the nitrogenous coefficient.

3. Advanced concepts of mathematical models

Dobbins (1964) assumed steady-state conditions for the stream and transformed from the temporal concept to a spatial version, including the effect of longitudinal dispersion (Eq. 7). However, he computed the effect of longitudinal dispersion and compared it to results obtained by neglecting such influence. He concluded that for fresh water streams the effect was negligible, and with the relationship $x/U = t$, the steady-state results were again expressed in units of time, t, and applied to actual river studies.

O'Connor (1967) introduced a mathematical model in which the photosynthetic effect of algae was placed in the temporal sense and all other sources and sinks remained in the spatial context. The relationship for algal productivity was given in Eq. 68, with the assumed 12-hr period and half sine wave being approximated with the first three terms of a Fourier series (Wylie, 1960, pp. 249-250). This yielded the following differential equation:

$$\frac{\partial D}{\partial t} + P_m \left(\frac{1}{2} \sin\pi \frac{t}{p} - \frac{2}{3\pi} \cos 2\pi \frac{t}{p}\right)$$
$$= - U_x \frac{\partial D}{\partial x} - rD + kL_a \exp[- j_r\phi(x)] + nN_a \exp[- j_n\phi(x)]$$
$$+ R + P_m/\pi + S \qquad (76)$$

where

P_m = amplitude of the diurnal photosynthetic cycle, considered constant spatially,

p = period of the half wave, 12 hr or 1/2 day,

U_x = stream velocity in the downstream direction, x,

$j_{r,n} = \frac{k_{r,n}}{U}$, relating temporal coefficients to spatial dimensions,

$\phi(x) = U \int_c^x dx/U_x$, U being the velocity at x = 0,

R = constant respiration rate of the algae, in terms of oxygen demand, and

S = volumetric oxygen demand of all bottom deposits.

All terms relating to the time dimension are contained on the left side of the equation, and all spatial derivatives are on the right. Solution and application of this mathematical concept depends upon evaluating the stream velocity relationships, it being assumed that velocity varies spatially but not diurnally. This concept was used by O'Connor to illustrate the fact that stream behavior is both a spatial and temporal relationship, in terms of diurnal effects at a fixed point, or longitudinal effects or response at a certain time.

The additional effect of nonconstant temperature conditions and changing DO saturation values were explored by Liebmann and Lynn (1966), and introduced into the basic Streeter-Phelps model. Frankel (1965a, 1965b) introduced diurnal fluctuations into a mathematical model incorporating the carbonaceous organic oxygen demand, benthal demand as a constant term, and the photosynthetic effect of algae. Diurnal fluctuations in BOD loading and in algae productivity were accounted for by expressing them in terms of hourly ratios of the daily mean, then using a small time increment in solution of the DO mathematical model.

The introduction of probabilistic models incorporating the oxygen balance model of Camp and Dobbins has been formulated (Loucks and Lynn, 1966). The probabilistic concepts permitted study of the chronological behavior of a stream during the critical low-flow periods, with the results being expressed in terms of probabilities of having less than the desired level of DO in the stream.

In the estuarine water environment, several advanced studies have been made. The method of systems analysis has been applied (Thomann, 1963, 1965; Thomann and Sobel, 1965; Sobel, 1965) to water quality problems primarily involving the movement of wastes in an estuarine environment. The physical system for which mathematical models are to be developed include three distinct components. These are the input, the output and the transformation between both components. For streams or estuaries, the principal inputs are waste effluents, the outputs are such water quality parameters as dissolved oxygen, organic waste load residuals, etc., and the transformation between components consists of the processes of flow, decay or oxidation, reaeration, diffusion or longitudinal dispersion, and sedimentation. If extended to management systems in addition to the physical systems, then the output would be the achievement of selected goals which satisfy the established criteria, based upon the input being programmed to physically represent the water environment and its reactions and responses, including a set of water quality goals. The transformation must be extended to include the physical environment (the stream), the economic environment (the costs relating to attainment of the desired goals), and within the existing institutional framework of constraints. As outlined by Thomann (1965), in qualitative terms

$$(\text{Transformation}) \xrightarrow{\text{on}} (\text{Output}) = (\text{Input})$$

and the dissolved oxygen model can be used as a typical illustration. As formulated by Thomann (1965) and in the terms used in this study, Eq. 44 can be expressed in terms of the spatial dimension, and Eq. 60

used to convert from the DO deficit to the spatial variation in DO content, yielding

$$U \frac{dC}{dx} + r\, C = r\, C_s - k\, L \qquad (77a)$$

This can be further subdivided into the differential operator notation and the right-hand side expanded to account for all sources and sinks as included in Eq. 74, giving

$$\left(U \frac{d}{dx} + r\right) (C) = \sum C_s,\ L_a,\ N_o,\ B,\ S,\ P,\ R \qquad (77b)$$

or

$$W(C) = f \qquad (77c)$$

where

W = differential operator acting as the transformation vehicle,

C = dissolved oxygen level, DO, desired as the output, and

f = all sources and sinks concerned with deoxygenation or reaeration, as indicated in Eq. 74, with the appropriate rate coefficients.

The output is then given by

$$C = W^{-1}(f) \qquad (77d)$$

for which Thomann defined W^{-1} as the reciprocal or inverse operation of differentiation, being integration. Thus, Eq. 77d is equivalent to Eq. 74, in abbreviated form, used in combination with Eq. 60. Of importance in its application to the stream environment is the direct proportionality existing between output response and the input levels, with the rate coefficients being the system parameters. As indicated by Thomann and shown in Eq. 74, each subportion of the system can be evaluated separately and summed to give the total output, agreeing with the principle of linear superposition (but limited to positive values of dissolved oxygen).

4. Summary

Each new input of waste effluents, along the stream, identifies a new reach for analytical purposes, with tributaries acting as positive or negative effluent points according to the magnitude of waste loads contained therein. Equation 1 applies to the reevaluation of concentrations of substances or water quality parameters. Appropriate models for dissolved oxygen (such as Eq. 74 or 77d) or organic waste loads (such as Eq. 75) can then be applied to provide output response for the new reach.

Appropriate notation and additional linearization of the final equations can be illustrated using the methods recently reported by Revelle et al. (1967, 1968). For a stream subdivided into n reaches, the DO deficit in the ith reach at the jth point in the reach (using the basic Streeter-Phelps formulation, Eq. 45 or 46) can be expressed as

$$D_{ij} = \left\{ \frac{k_i}{r_i - k_i} [\exp(-k_i t_{ij}) - \exp(-r_i t_{ij})] \right\} L_i + [\exp(-r_i t_{ij})] D_i \qquad (78a)$$

or

$$D_{ij} = f_{ij} L_i + g_{ij} D_i \qquad (78b)$$

where

D_{ij} = DO deficit in the ith reach at the jth point in the reach,

L_i, D_i = values of BOD and DO deficit at the beginning of the ith reach,

r_i, k_i = rate coefficients for the ith reach,

t_{ij} = time of travel from the beginning of the ith reach to the jth point in the reach, and

f_{ij}, g_{ij} = linear reduction factors for t_{ij} in the ith reach, as applied to L_i and D_i.

Because of the ability to superimpose the response of additional inputs, Eq. 78b was subsequently extended to include the effects of additional uniform BOD contributions along the stream and sedimentation-scour effects. Revelle et al. (1968), using similar notation, expressed the rate of reduction of organic wastes, or the remaining BOD, in the ith reach at the jth point in that reach as

$$L_{ij} = \exp(-\,k_i t_{ij})L_i = h_{ij}L_i \tag{79}$$

This technique provides the point by point and reach by reach solution for both the dissolved oxygen (DO) and biochemical oxygen demand (BOD) levels in the stream.

The physical response of the stream environment, as expressed in the combination of individual responses of the several sources and sinks of residues and substances, can therefore be expressed as a mathematical model. Particular or specific responses, or the nature of the substance (whether conservative or nonconservative), determines the nature of the mathematical model to be used. The complexity of the several models needed to represent the composite response will depend on the physical data and nature of the stream being studied. The desired attribute noted by Theriault (1927) for mathematical representation of the physical systems observed in laboratory studies was the selection of the simplest method which will simulate the observed physical response within a desired degree of accuracy. The physical response, once adequately described, can be used subsequently in forecasting studies or in water quality management studies in which economic aspects play the important role.

G. Miscellaneous Other Considerations

1. Conservative substances

The concentration of conservative substances that are stable in the stream environment, such as salts or chlorides, etc., can be evaluated using Eq. 1 for steady, uniform flow conditions. If the discharge varies temporally or spatially, then additional analysis is required. Equation 1 may be used for short increments of distance or time, or more refined techniques and mathematical models can be derived. Longitudinal dispersion effects may be involved, as illustrated in the development of Eq. 7. O'Connor (1967) has evaluated some of the variations which can arise temporally or spatially as the discharge varies downstream of the point of effluent discharge. Again, formulation of specific and applicable models depend upon the initial and boundary conditions which are encountered in actual field studies.

2. Bacterial die-away

Evaluation of the levels of infectious agents remaining in the stream water downstream of a point of effluent discharge has been treated mathematically. Phelps (1944) referred to this effect as bacterial self purification by the stream environment. Once maximum bacterial numbers are reached, the exponential die-away concept has been applied to simulate the observed reduction of bacterial numbers with time:

$$\log \frac{B}{B_o} = - K_b t \qquad (80a)$$

where

B = final number of bacteria, after a time, t,

B_o = initial number of bacteria, and

K_b = die-away coefficient, per day, base 10.

However, as noted previously in the historical review, there is a general tendency for bacterial numbers to increase during an initial time period following discharge to the stream, and in addition the die-away rates are temperature dependent (Phelps, 1944; Kittrell and Furfari, 1963; Berg et al., 1966).

Phelps (1944, p. 211) noted that a more adequate simulation of observed stream behavior was obtained by dividing the initial number of bacteria, B_o, into a less resistant portion and a more resistant portion and applying the exponential decay equation to each portion. A separate coefficient must be evaluated for each group.

In order to include the variations in the rate of die-away observed in natural purification, the following mathematical model was introduced (Fair and Geyer, 1954; Fair et al., 1968):

$$\frac{B}{B_o} = (1 + nkt)^{-1/n} \tag{80b}$$

where B, B_o, and t were defined above,

k = initial die-away coefficient (base e) for a specific bacterial group identified for study in the stream environment, and

n = associated coefficient of nonuniformity of the coefficient k.

If n = 0, then the two equations are identical, with K_b = 2.3 k. The same limitations concerning the increase in bacterial numbers in the initial reach of the stream below the point of discharge would apply also to the second equation.

3. Summary

The mathematical models which have been included in this brief review and discussion represent the ones which have been formulated and used in stream behavior studies. Additional relationships have been and are being studied today under controlled laboratory conditions, as any review of the literature will disclose. Because of a lack of verification in actual field conditions, or introduction of coefficients that may be different in the stream environment, these have not been included in this study.

Variations in the levels of quality influenced by radioactive substances or heat could be approached using the exponential decay concepts. No additional consideration was given to these potential pollutants in this study, since the general approach to the decay or die-away problem has been made and specific application would have to consider the various problems and limitations that have been noted.

VI. THE ECONOMIC DIMENSION

A. Application of Economic Principles

Economic evaluation is a method of comparing competing alternatives among desired programs, and such evaluation has been a part of water resources development since the first public project was initiated (Water Resources Policy Commission, 1950). As noted by Ciriacy-Wantrup (1964), this evaluation provides a framework from which political decisions are made regarding resource allocation and use. Economic evaluation in quantitative terms of the various alternatives available in constructing water quality improvement programs will provide a comparative if not an actual basis for decision making.

According to Thursby (1966), systematic economic evaluation consists of

> (1) demand analysis to determine which, if any, service area to serve;
>
> (2) benefit/cost analysis – or economic justification-to determine:
>
> a. which project;
>
> b. what size;
>
> c. when to build it;
>
> (3) cost allocation analysis to determine which project purposes, and which users, should be assigned the costs; and
>
> (4) financial feasibility analysis to determine:
>
> a. the source of first instance capital; and
>
> b. the source of revenue to repay that capital.

The economic models used in making these evaluations will be discussed in this section. Four aspects of the economic dimension will be dealt with: (1) the general considerations of benefits and costs of water quality control as affected by implementation of stream water quality standards, (2) simple economic models for single polluters, or for a very few, (3) additional concepts of cost minimization studies and linear programming methods, and (4) a review of the river basin studies that have been made for water quality improvement.

B. Benefits and Costs of Improving Water Quality

1. Definitions and basic problems

Benefit-cost analysis requires quantification of the variables in both physical and economic terms, with money as the common denominator. The problem of evaluating benefits and costs in water resources has been the subject of intensive study and discussion (Water Resources Policy Commission, 1950; Federal Inter-Agency River Basin Committee, 1950; McKean, 1958; U.S. Senate, 1962; Smith and Castle, 1964; Kneese, 1966). Arrow (1965) noted that three major problems in benefit-cost studies were (1) discounting future benefits, (2) measurement of benefits, and (3) measurement of costs. The most recent expression of the federal government is found in Senate Document 97 (U.S. Senate, 1962), with its supplement. A differentiation among tangible and intangible benefits, and primary and secondary benefits, was made:

> 1. Benefits: Increases or gains, net of associated or induced costs, in the value of goods and services which result from conditions with the project, as compared with conditions without the project. Benefits

include tangibles and intangibles and may be classed as primary or secondary.

2. Tangible benefits: Those benefits that can be expressed in monetary terms based on or derived from actual or simulated market prices for the products or services, or, in the absence of such measures of benefits, the cost of the alternative means that would most likely be utilized to provide equivalent products or services. This latter standard affords a measure of the minimum value of such benefits or services to the users.........

3. Intangible benefits: Those benefits which, although recognized as having real value in satisfying human needs or desires, are not fully measurable in monetary terms, or are incapable of such expression in formal analysis......

4. Primary benefits: The value of goods and services directly resulting from the project, less associated costs incurred in realization of the benefits and any induced costs not included in project costs.

5. Secondary benefits: The increase in the value of goods and services which indirectly result from the project under conditions expected with the project as compared to those without the project. Such increase shall be net of any economic nonproject costs that need be incurred to realize these secondary benefits.

Water quality control benefits were described as:

...The net contribution to public health, safety, economy, and effectiveness in use and enjoyment of water for all purposes which are subject to detriment or betterment by virtue of change in water quality. The net contribution may be evaluated in terms of avoidance of adverse effects which would accrue in the absence of water quality control, including such damages and restrictions as preclusion of economic activities, corrosion of fixed and floating plant, loss or downgrading of recreational opportunities, increased municipal and industrial water treatment costs, loss of industrial and agricultural production, impairment of health and welfare, damage to fish and wildlife, siltation, salinity intrusion, and degradation of the esthetics of enjoyment of unpolluted surface waters, or conversely, in terms of the advantageous effects of water quality control with respect to such items. Effects such as these may be composited roughly into tangible and intangible categories, and used to evaluate water quality control activities. In situations where no adequate means can be

> devised to evaluate directly the economic effects of water quality improvement, the cost of achieving the same results by the most likely alternative may be used as an approximation of value.

Measurement criteria for the other beneficial uses of water were included. Recreation benefit criteria were presented in a supplement, permitting monetary values to be attached to recreation, as based on a visitor-day concept.

The concept of including secondary benefits has been much discussed and criticized (McKean, 1958; Ciriacy-Wantrup, 1964) because of the danger of double counting benefits and the doubtful nature of secondary benefits being gains to the composite economy of the nation. McKean noted that of the three major federal construction agencies (Bureau of Reclamation, Corps of Engineers, and Department of Agriculture) only the former counts secondary benefits in program evaluation.

Dutta and Asch (1966) prepared a report for the Delaware River Basin Commission concerning the measurement of water quality benefits. The study was undertaken to develop the most applicable technique for measuring in dollar terms the value of various levels of water quality. Three classes of benefits were recognized, according to the type of measurement problem that existed:

> (1) Loss-avoidance benefits. These possess the virtue of being readily measured. Failure to improve water quality will necessitate a definite expenditure of resources, which constitute the loss or cost to be avoided.
>
> (2) Other readily measured benefits. Although not necessarily reducing current or future costs, these benefits relate generally to the economic impact of water quality on various industries and land use along a polluted stream.

(3) Recreation and esthetics. These are activities for which measurement methods and quantitative evaluation are not clearly defined.

2. Economic alternatives and benefit-cost studies

The federal Water Pollution Control Act, as amended July 20, 1961, established low-flow augmentation for water quality control as a nonreimbursable purpose of federal multipurpose water resources systems. However, it was definitely stated that this beneficial use could not replace the need for necessary and adequate waste treatment. The current technique used by federal agencies involves estimating costs and benefits from reservoir storage for water quality control as the "least costly single purpose alternate plan method" (Grounds, 1967). Adequate treatment prior to dilution by augmented low flows was considered to be in the range of 85 to 90% removal of BOD and suspended solids, unless a greater efficiency was indicated. This technique means that the cost of constructing a single purpose storage reservoir for water quality control becomes the benefit in benefit-cost analysis of multipurpose reservoirs. The method was used in studies of the Potomac River basin, and more recently for the proposed Ames Reservoir in Iowa (U.S. Corps of Engineers, 1963, 1964).

However, this is just one of the 11 physical methods of achieving control of pollution (National Academy of Sciences, 1966b) outlined previously. Both the need for and the results of considering some of the alternatives have been included in recent publications (Kneese, 1964; Davis, 1966). In many of the situations which were restudied, more economical alternatives to low-flow augmentation were discovered.

The relationship of the time profile of benefits and costs to water quality management decisions may also be important (Parker and Crutchfield, 1968). Their studies indicated that long-term benefits can contribute under special circumstances to a greater present worth of accrued benefits over the life of a project than normally expected. This would be true if pollution by one user precluded benefits from one or more alternative uses that would have shown a significantly higher growth rate over time, thus failing to account for the full social costs of long-term reductions in water quality. The term social cost was defined as "the net loss of benefits that would have accrued if the water in question had not been used for waste disposal." Thus, the costs of prevention and/or abatement and the opportunity costs of foregone benefits, or benefits reduced by lower water quality must be included in the aggregate of costs of water pollution control. Kneese (1962, pp. 30-31) aspired to the same goal, but noted the lack of real world data. If all relevant alternatives are introduced into this aggregate cost analysis, Parker and Crutchfield indicated an optimal mix at the point of lowest aggregate cost. Using three models, for benefits (1) constant with time, (2) increasing at a linear rate, and (3) increasing at a compounding rate, it was illustrated that an increasing proportion of the project benefits accrued during the later years of the assumed 100-yr design period for the latter two rates. The importance of careful evaluation of the time stream of benefits in water pollution control programs was emphasized, it being noted that the preclusion of other uses predominated in the use of the water environment for waste disposal. The growth of recreation in recent years was used to illustrate the emergence of a latent use of water resources.

Meaningful benefit-cost studies have only been possible in river basins where substantial data are available. The Ohio River, used heavily for municipal and industrial water use, transportation, pollution control and recreation was the subject of an annual benefit-cost analysis by Bramer (1966). Gross national product (GNP) data were used to estimate the annual value of the surface water use, and the effects of water quality on withdrawal and nonwithdrawal water use values. Additional estimates of pollution abatement costs were made, and the results as given by Bramer are shown in Fig. 4. The stepwise effect, for uniform treatment at the primary treatment level first and then the secondary level, is evident in both the cost curves and the benefit curves. For the relative cost study which was made, the results indicated that annual costs always exceed the benefits. If some water quality improvement is desired, then public subsidies would be kept to a minimum with a reduction of the pollution load to the 40 to 80% level.

Goodman and Dobbins (1968) developed a mathematical model for a hypothetical river basin that was based on benefit-cost concepts. The model would evaluate the total annual benefits and costs for three competing uses of the water environment: water treatment from the surface source, recreation use, and water quality control using waste treatment plants. Required data include the parameters representing the assimilative capacity of the stream, cost of construction and operation of plants, recreation use and value data, and the constraints

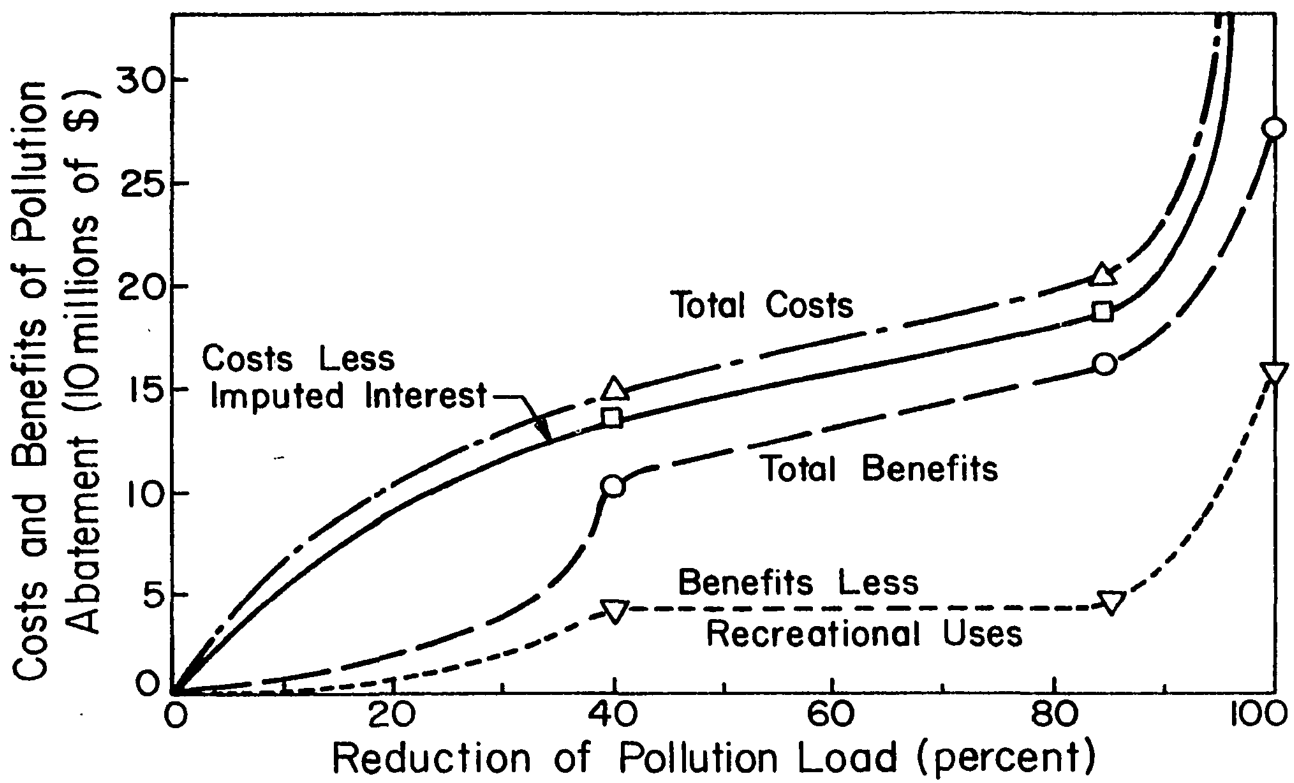

Fig. 4. Results of an annual benefit-cost analysis of pollution abatement for the Ohio River basin (after Bramer, 1966).

to be applied. The model as applied to the hypothetical river basin illustrated that maximum net benefits did not occur under the requirements of uniform treatment standards.

In the absence of an effective market mechanism and with a lack of ability to measure accurately all benefits in dollar terms, alternatives in the method of approach have been suggested (Kneese, 1962, 1964). Public policy goals (nonmarket oriented) or objectives, as expressed through explicit judgment, are imposed on the water quality problem. The distinction between objectives and constraints, noted Kneese, should be observed in establishing the policy. Dorfman (1960) explained that

> A requirement is a constraint if (a) it must not be violated at any cost however high or with any probability however low, and (b) if there is no gain or advantage in overfulfilling it. On the other hand, a requirement is one of the objectives of the firm if it can be violated, though at a cost or penalty, or if there is an advantage in overfulfilling it.

Within this concept, Kneese considered the implicit goal of "clean water" an objective, but the explicit designation of a minimum of 5 mg/l DO as a constraint. Therefore, cost minimization studies which consider the explicit constraints of public policy become a focal point. These constraints can then be tested for the sensitivity of costs to them. This provides a cost minimization framework for economic studies (Kneese, 1962).

C. Economic Principles Relating to Water Pollution

1. Marginal economic analysis applied to individual polluters

Economic analysis for minimizing the social cost of pollution is simplified if the problem is reduced to only one or at most a few polluters, as shown by Kneese (1964) and Timmons (1967). A basic understanding of the diseconomies of pollution becomes more evident. In this manner, also, the principles of marginal analysis can be applied using assumed or actual production functions and output values. The optimum allocation of the water resource for the given conditions (or the level of water quality at which cost minimization is achieved) can then be shown.

A summary of the approach used by Kneese (1964) can be used to illustrate the economic effect of water pollution under these circumstances. The marginal cost and damage (or loss avoidance) curves are shown in Fig. 5 for this example. It is assumed that an industrial firm (or a municipality) is located upstream of a reach in which commercial fishing predominates as a revenue producing entity. The fishing industry realizes a net annual return of Y dollars per affected reach. Its fishing equipment is considered to be a transferable resource, with the net return of Y dollars representing a 10% return on the transferable floating investment, no fixed shore investment being considered. As additional units of waste (i.e., thousands of pounds of BOD) are discharged to the river, a constant incremental net value of fish harvest would be lost. At the assumed level of production, the industrial firm would produce OD units of waste discharge. The incremental cost of

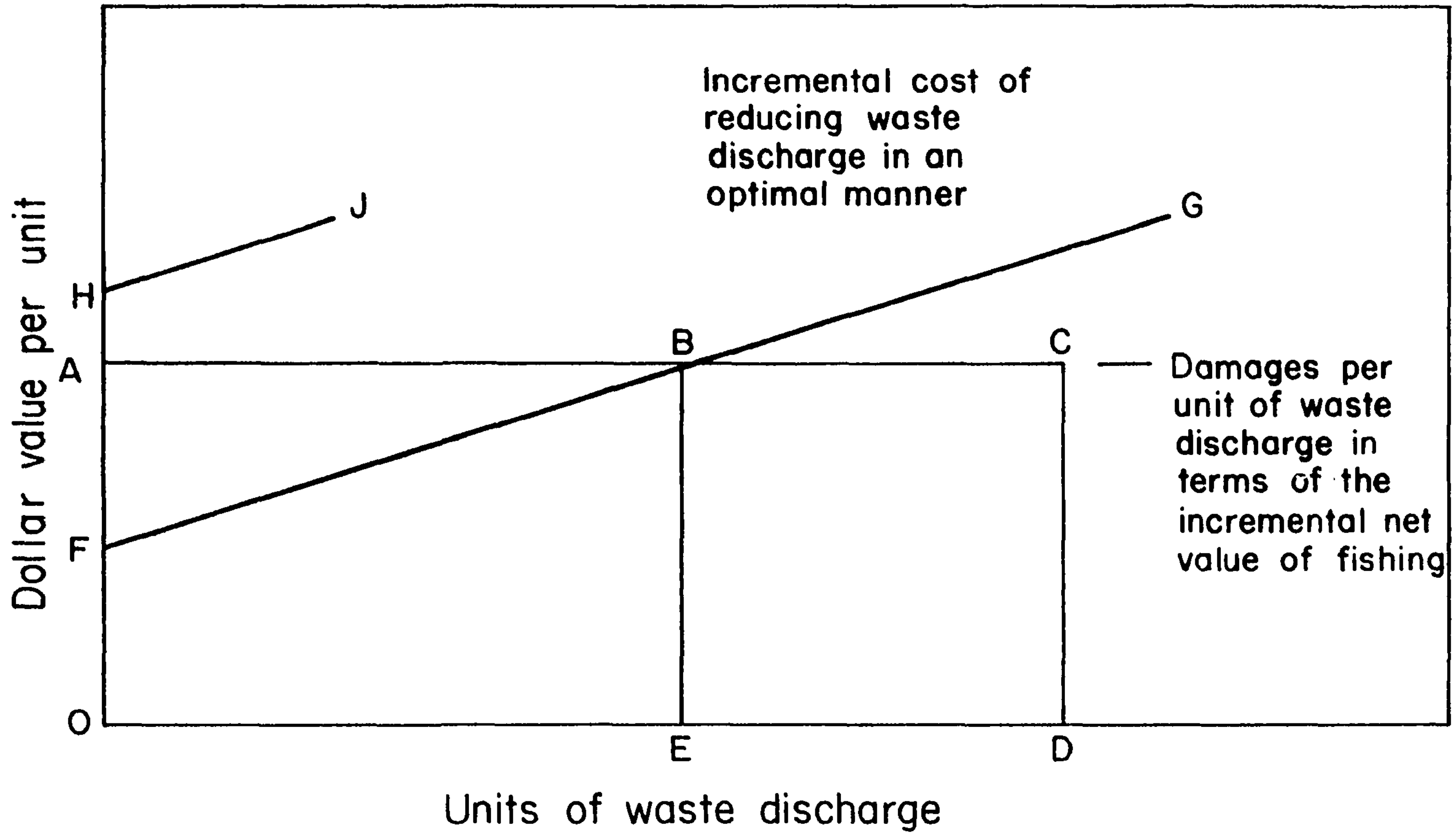

Fig. 5. Response of an individual firm which is accountable for the level of water quality in the stream (after Kneese, 1964).

reducing the waste load by some one or more combinations of the 11 designated technical processes (listed previously) is shown by the line FG. The additional increments are assumed to vary in a linear fashion for the purposes of this example.

In terms of economic theory, Kneese noted first that the fishing industry would be willing to pay annually an amount up to Y dollars to prevent pollution from influencing adversely the affected reach, sacrificing a part or all of its net return. The industrial firm could either accept the amount Y and provide additional waste treatment, or refuse and eliminate the fishing in that reach. In making the latter decision, if it is making rational decisions, the firm has determined that it would cost more than Y dollars annually to do so. On a total value basis, the industrial firm's cost saving plus the value of the production achieved by the fishing industry after relocating is greater than the value of continued fishing in the reach. Kneese noted that the same decision would be reached if effluent charges (through some public agency) had been imposed as the offsite social cost. For both circumstances, the net value of the fishing industry's take can be labeled as the "opportunity cost," in the allocation of resources. Income distribution is different, however, and the fishing industry may not be favorably disposed to the reduction in net value or in relocating. In addition, Kneese noted that if the fishing industry can be transferred (or its floating equipment used in another occupation returning annually Y dollars on the investment of 10Y dollars), then the social cost of the pollution or reduced water quality is Y dollars (and not 110% of Y, the gross market value of the fish under perfectly competitive circumstances).

The maximum effect of the waste load would reduce the output of fish by the gross amount, but the transferred fishing industry could presumably recoup the annual value of its output.

This either-or situation can be made more realistic by considering the incremental analysis shown in Fig. 5. In this situation the industrial firm can regard the net offsite cost of inadequately treated wastes as an opportunity cost. The incremental cost of constructing and operating an optimum waste treatment plant is given by FG. The damage (or reduced net return) cost to the fishing industry per unit of waste discharge is OA. If the industrial firm either is charged an amount OA for each unit of waste discharged, or alternatively, is paid OA by the fishing industry, the firm will be induced to reduce its waste discharge by the amount OE, leaving a residual amount ED. At this point, the firm will save the amount ABF, since OABE represents the total damages or loss of fishing revenue avoided (or total effluent charge), and OFBE is the integrated marginal cost of the treatment process. Therefore, the industrial firm has a net saving or a net revenue of ABF. Beyond the point E, it is less costly for the firm to discharge wastes and either pay the penalty or forego the payment.

Kneese (1964) also noted that at point E total costs attributed to pollution control, abatement costs added to damage costs were at a minimum. This total cost is equivalent to the area OFBCD. Additional increments of pollution control would cost more that the residual damages prevented (Area OFBCD would increase above the line BC in the region CBG, or total costs would increase). Less treatment than that indicated at point E would decrease the savings ABF accruing to the firm, or total costs would again increase. If the damages avoided are considered as benefits and the pollution control through waste treatment as a cost, net benefits are maximized at point E. For this simple case, cost minimization and net benefit maximization are the same.

This analysis is applicable only if the incremental cost curve FG lies below the constant level damage relation AC. If the incremental cost of reducing waste discharge increases to the stage shown by HJ, then the problem degenerates to one in which no waste treatment is forthcoming, in an economic sense. Such real world problems have confronted the policy maker, making necessary the concept of incentives and financial assistance. However, unless the economic analysis is made, information is not available for such decision making.

2. Pollution affecting more than one beneficial use of water

Application of marginal analysis can be extended to the case of one or more polluters affecting more than one water use. The incentive to move in the direction of the optimum was achieved by Kneese (1964) through the process of "internalizing" the external diseconomies. All of the relevant water uses were controlled by one firm, and each use was beneficial and productive. Kneese (1964) described the economic principles and equations which apply to marginal analysis with such a combination, and Frankel (1965a, 1965b) applied an engineering-economic model for it in a hypothetical situation but using observed stream data for a California stream.

The general concepts as given by Kneese are shown in Fig. 6. The abscissa indicates the degree of waste treatment, corresponding to

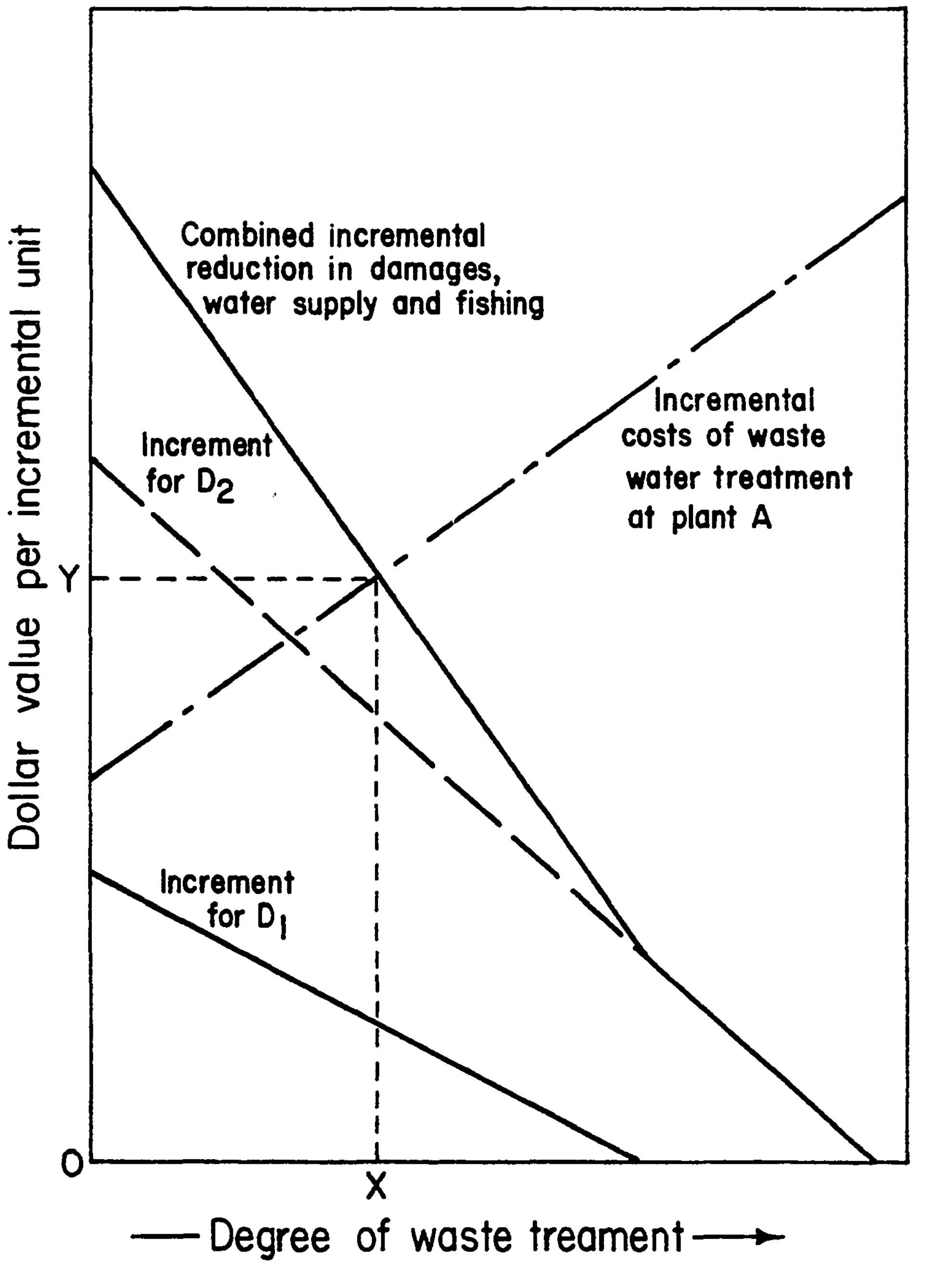

Fig. 6. Response of a firm controlling three beneficial uses of water that are influenced by the degree of waste treatment (after Kneese, 1964).

selected levels of stream water quality that influence the other beneficial uses. The ordinate represents the incremental costs involved, either as damage values or waste treatment costs. The three water uses include recreation (with access and the water surface area controlled by the firm), water supply (industrial plant B of the firm, located downstream of the waste treatment plant), and water quality control (through operation of the upstream waste treatment plant A of the firm). The incremental damage and cost curves are shown for the total damage and cost functions D_1, D_2, and WTC. These curves, linear for simplicity, illustrate the marginal reduction in value for incremental increases in water quality improvement. The independent damage functions can be added vertically to obtain the combined incremental effect of damage reduction. For the downstream plant, the damage reduction is reflected in loss of production or in increased treatment costs. Incremental costs of waste water treatment show how the total treatment costs would increase as water quality is improved in the stream. The optimum water utilization is achieved at point X, as noted by Kneese, where marginal cost of additional waste water treatment equals the combined marginal damage value (benefits from loss-avoidance).

The simplified linear analysis of Fig. 6 can be expressed in mathematical terms for the general situation. The controlling firm is faced with two damage functions, D_1 and D_2, and a cost of waste water treatment function, WTC. The degree of waste treatment, or reduction of pollutant concentrations discharged to the stream, is labeled as R. As summarized by Kneese, the formulation in a mathematical model is

$$D_1 = f_1(R) \qquad f_1' < 0 \tag{81a}$$

$$D_2 = f_2(R) \qquad f_2' < 0 \tag{81b}$$

$$WTC = f_3(R) \qquad f_3' < 0 \tag{81c}$$

The objective function requires the sum to be a minimum

$$Z = D_1 + D_2 + WTC = f_1(R) + f_2(R) + f_3(R) \tag{82a}$$

which requires setting the first derivative to zero,

$$\frac{dZ}{dR} = f_1'(R) + f_2'(R) + f_3'(R) = 0 \tag{82b}$$

and in addition

$$\frac{d^2Z}{dR^2} > 0 \tag{82c}$$

This provides the mechanism for evaluating the optimum level of water quality for the concept of minimizing the costs associated with water pollution control. Timmons (1967) presented a similar graphical model using the total cost functions in place of the incremental or marginal costs. Actual use depends upon the ability to express the three functions quantitatively, and implies adequate technical knowledge of production processes and the response of the streams to waste inputs.

Whipple (1966) agreed with the incremental analysis presented by Kneese, but believed that the firm would use average cost over the long run in contemplating new plant locations in preference to marginal costs. For the production life of the plant, the average cost was considered as the marginal cost for decision making purposes. Thus, a difference would then arise as to whether pollution control might best be achieved by an effluent charge or by an effluent-reduction bonus.

3. <u>More complex interactions</u>

a. <u>Three firms interacting with water quality levels</u> Whipple (1966) presented an extension of Kneese's incremental approach beyond the level of two plants to include a third plant. To achieve optimum results, it was his objective to show that a new industry or enlarged activity of present plants should be charged fully for the total costs which would be incurred in the basin. The graphical concepts of this analysis are shown in Fig. 7. He first considered two existing plants which had arrived at the optimum operating level. The water quality relationships are shown in Quadrant I of Fig. 7. Plant X, located upstream of plant Y, can provide varying degrees of waste treatment, with the incremental costs shown by R_x, as a reduction of waste load discharge by the plant. Plant Y is affected by the level of wastes in the river, and the costs associated with acceptance of varying degrees of water quality are included as A_y. According to marginal cost theory, the optimum point for minimum total cost of pollution control is at point B, with each firm experiencing incremental costs of OA = BC, and with a waste load in the river of OC or W_1. Area OBFC represents the total cost to both firms, with OBC being accepted by firm Y and BFC by firm X. The cost for plant X is for waste water treatment, and that for plant Y is for increased water supply costs, reduced output, or some other damage avoidance costs.

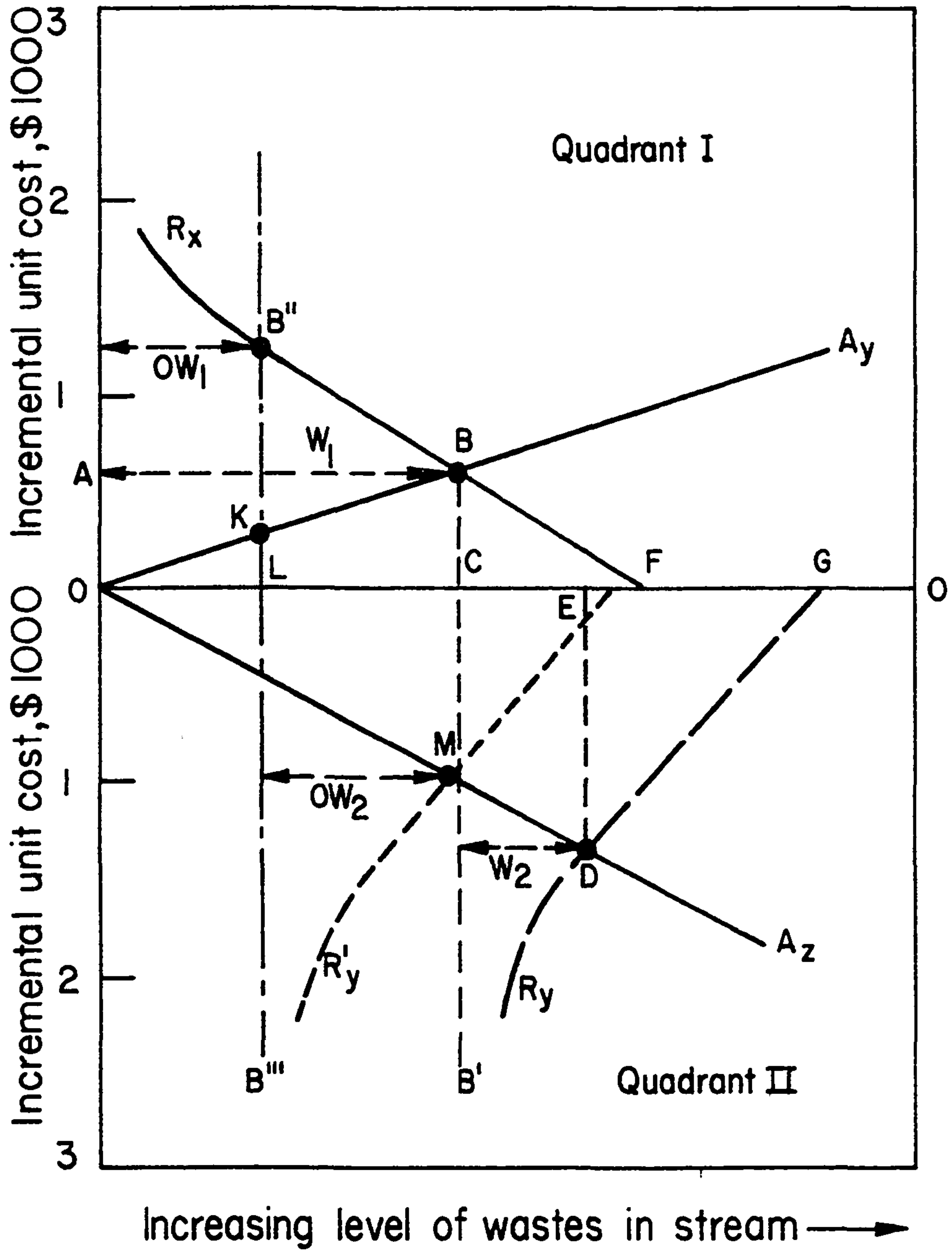

Fig. 7. Effect of entrance of a third firm in the reach of a stream where two existing firms are located (after Whipple, 1966).

Whipple (1966) then permitted a third plant to locate on the stream, at a point downstream of plant Y. The latter, plant Y, is now located in the middle of the other two, and its waste discharge is now presumed to influence the cost of production at plant Z. The effect of plants X and Y in increasing the waste load in the stream is reflected in increased costs of accepting poorer water quality at plant Z, and is shown in Quadrant II of Fig. 7 as A_z. With line BB' representing the level of wastes in the stream under existing conditions prior to the entry of plant Z, this line serves as the reference line for plotting the incremental waste treatment costs of plant Y, shown then as R_y. Whipple showed that if W_1 remained inflexible, then plants Y and Z would reach an optimum pollution control level at point D, with added waste level of CE or W_2. The water quality level in the stream would then be at OE. Plants Y and Z would each experience incremental costs of DE at the inflexible operating level, per unit of waste.

However, it was noted that point D was not the true optimum for the reach of the stream containing the three plants. If W_1 is decreased by a small amount (dW) by providing additional treatment at plant X, then the additional treatment cost is given by BC • (dW). This would shift the line BB' and the R_y cost line a distance (dW) to the left, and would decrease the cost of acceptance of plant Z by the amount A_z(dW) = DE • (dW). Because DE is greater in magnitude than BC, a net reduction in total costs is achieved. Obviously plant Y benefited by the move (dW) to the left, since lower values of A_y and R_y are obtained. Mathematically, the shift of line BB' to the left an amount (dW) increases the cost to plant X by the amount R_x • (dW) and decreases the acceptance cost to plant Y by the amount $A_y \cdot dW$. The corollary shift in R_y decreases the acceptance cost to plant Z by $A_z \cdot dW$. The optimum for the three plants will be reached when the incremental increase in costs to plant X equals the decrease in incremental costs at plants Y and Z, or when the incremental costs are equal. Therefore the new optimum for three plants is given by

$$R_x dW = A_y dW + A_z dW \quad \text{or} \quad R_x = Z_y + A_z \qquad (83)$$

The new optimum is found, in Fig. 7, by reducing W_1 (which shifts both BB' and R_y to the left) until Eq. 83 is satisfied. This optimum solution for three plants is shown as OW_1 at point B" for plant X and OW_2 at point K for plant Y. Plant Z is operating at point M. The total cost for plant X is the vertical area beneath FB", and the costs of the other two plants are computed in a manner similar to that described before. Whipple noted that this increased the costs of treatment considerably for the upstream plant, but an equally large reduction in total reach cost of water pollution control was achieved. He concluded that in principle a new optimum position should be determined for each new plant or addition to existing plants added to the system. In addition, each new plant should be assessed a penalty charge equal to the increased total costs which is imposed on the others at the new optimum position.

b. <u>Results of an engineering-economic model study</u> Frankel (1965a, 1965b) used the two plant system, an upstream waste treatment plant and a downstream water treatment plant, as the basis for developing an engineering-economic model. With the mathematical model, water treatment costs could be evaluated as a function of water quality in the stream, as the stream was affected by varying degrees of waste treatment at the upstream location. Water quality parameters included in the model (data obtained through an intensive literature review or from additional experimental studies) were BOD, dissolved oxygen, coliform bacteria, and detergent concentrations. The general procedure for the detailed study was described as

> ...It was assumed that water quality downstream from the point of disposal would be treated by conventional water treatment for municipal water supply. Pollutant concentrations were first recorded for each streamflow, for specific distances downstream, and for each treatment process considered. Concentrations were then converted to chemical dosages required (if any) to reduce the pollutant to the specified quality level either set by water treatment operating standards or U.S. Public Health Service Drinking Water Standards. Chemical requirements were converted to dollars and cents and additional operation and maintenance costs plus capital investment costs (if any — both as explained in costs of water treatment) were added to chemical costs to obtain total additional costs of water treatment operation.....All costs were handled on an annual basis since multiplication by probability of occurrence yields an average annual cost if the entire spectrum of probability is considered.

Among the solutions obtained in the study was an evaluation of downstream water treatment cost savings for additional increments of upstream investment in waste treatment facilities. Frankel concluded

> ...the additional average annual costs of water treatment decrease as the level of treatment of domestic sewage increases upstream. The amount of savings downstream is a direct benefit of the additional costs of sewage treatment upstream. A ratio of cost savings to downstream water treatment plants (by change in treatment of upstream sewage treatment plants) to the cost of change of upstream sewage treatment plants can be calculated in a similar manner to the benefit-cost ratio utilized in evaluating the worth of water resources projects......The cost savings to additional cost of treatment ratio is quite small for all cases and varies between zero and 0.106. The ratio increases for larger sewage treatment plants since economies of scale favor the higher performance plants and since cost

> savings are greater for larger sewage loads. The ratios also indicate that the maximum return per investment dollar (in terms of cost savings to downstream municipal water treatment plants) is realized when secondary treatment is added to primary treatment and when points of use are close together.

The sizes of plants used in the study were 2.5 and 10 mgd for each type, water treatment and waste water treatment.

The average annual costs of meeting selected DO levels and in reducing coliform bacteria were also determined, to illustrate the cost evaluation of stream water quality standards through increased treatment of wastes. Both the Eel River in California and a hypothetical stream were used in the study. Design flows were varied, from the once-in 5-yr, 7-day flow to the more rare events, including the 10-yr, 20-yr and the lowest flow of record for the stream studied. No increase in average annual costs of waste treatment, expressed in percent, was experienced for the 5 mg/l DO level until the once-in-20-yr frequency level was reached. A 5% increase in costs resulted for the once-in-20-yr event. A 25% increase in annual waste treatment costs occurred if the design level was established at the lowest flow of record, for a 5 mg/l DO level. The comparable costs of waste treatment were $73,000 and $225,000 annually for cities of 25,000 and 100,000 population, based upon the stream characteristics of the Eel River. Only primary treatment with chlorination was required in the case study because of favorable stream conditions. Because water treatment costs are associated closely with the concentrations of pollutants, and the latter are well diluted at higher stream flows, Frankel used the stream duration curve and the related probabilities of experiencing selected discharges in evaluating the increase in annual cost of water treatment. Evaluation of increased annual water treatment costs showed they were not significantly reduced, even when raw wastes were discharged during high flow periods (14% increase for the hypothetical system of two cities but using the Eel River data).

c. An isoquant-isocost approach Bramhall and Mills (1966) applied the isoquant-isocost approach to production theory in a study of the alternative methods of improving stream water quality. The tradeoff between waste water treatment and low flow augmentation from reservoir storage was examined by constructing "isoquality" relationships between the two alternatives. As defined by Leftwich (1960), an isoquant indicates graphically the various combinations of two resources that can be used to produce equal amounts of output or product, and in general is the same type of curve as an indifference curve for consumer consumption. Isoquants are usually convex to the origin, illustrating that the two resources are not perfect technical substitutes (the principle of diminishing marginal rate of technical substitution of one resource for another).

The application of this technique to produce isoquality lines for substitution relations between additional waste treatment and low flow augmentation can be described from the work of Bramhall and Mills (1966). Hypothetical relations are shown in Fig. 8. Each isoquality line indicates the combinations of waste water treatment and low flow augmentation that provide a given stream water quality standard. The dissolved oxygen level was selected to represent water quality in the stream. Each curve also implies constancy in (1) total amount of waste produced,

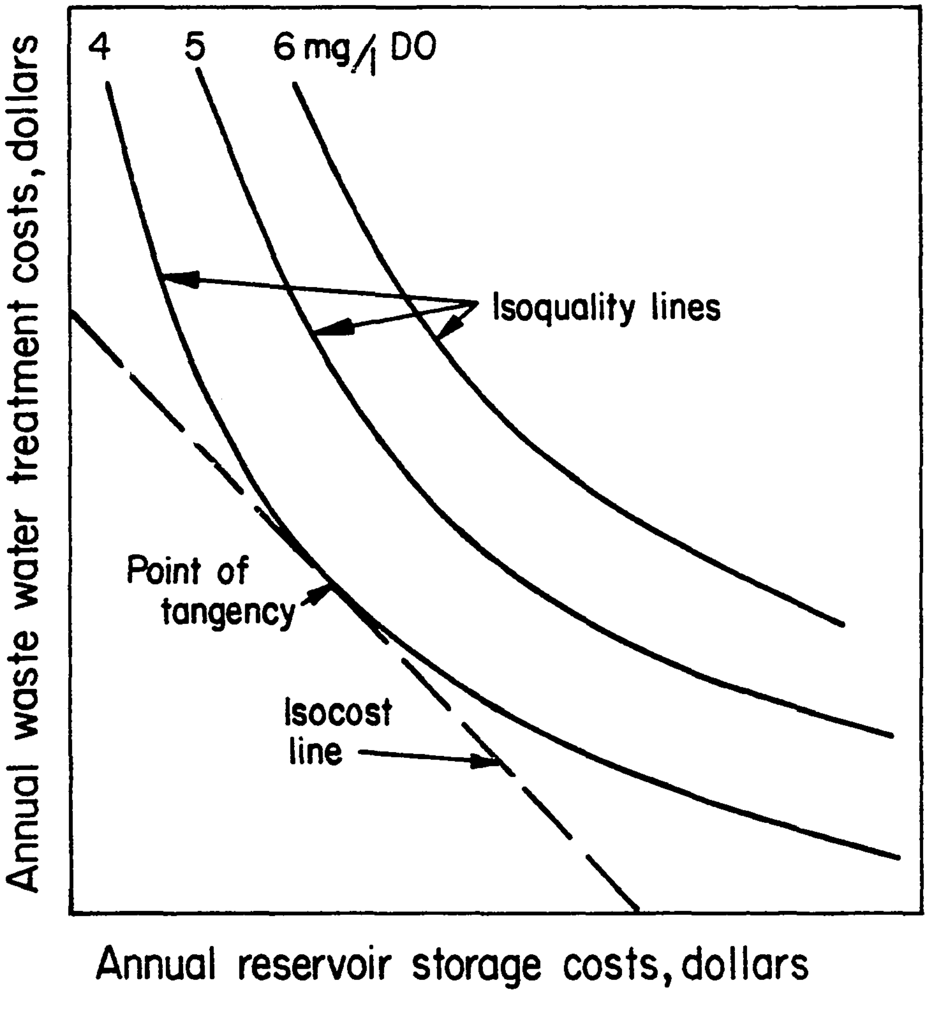

Fig. 8. Hypothetical substitution relations between two water quality improvement alternatives (after Bramhall and Mills, 1966).

(2) level of aggregate streamflows without storage, and (3) the assimilation ratio or self purification factor for the stream. Construction of an isoquality line depends upon the ability to formulate the treatment cost function, the storage-yield function for reservoir storage, the storage cost function, and the streamflow-waste assimilation relationship.

Both axes measure annual costs in dollars, for both waste treatment and reservoir storage. A line connecting equal costs (slope of minus one for equal scale factors) on the respective axis is the isocost line, representing combinations of waste water treatment and low-flow augmentation that have the same total cost. The point of tangency between the isoquality line representing the desired water quality and the lowest possible isocost line then identifies the optimum combination of the two alternatives and the total cost involved to reach that water quality level.

All functions were expressed in linear form by Bramhall and Mills to facilitate the development of a simple mathematical model for the isoquality lines. Additional simplification of other relationships was required also, including the assimilation capacity, minimum streamflow prior to augmentation, gross storage-yield ratios, etc. The waste treatment cost function was expressed as

$$Q_T = -\frac{a_1}{b_1} N + \frac{1}{b_1} C_T \qquad (84)$$

where

Q_T = amount of waste reduction by treatment,

N = the total initial amount of waste, in PE's,

C_T = annual cost of treatment, total cost, in dollars,

a_1 = the annual fixed cost of a unit of plant capacity, and

b_1 = marginal cost of treating additional waste.

The three relationships leading to the cost function for low-flow augmentation were

$$Q_S = b_2 F \tag{85a}$$

$$F = I - \frac{a_3}{b_3} + \frac{1}{b_3} S \tag{85b}$$

$$S = - \frac{a_4}{b_4} + \frac{1}{b_4} C_S \tag{85c}$$

where

Q_S = amount of waste reduction achieved by stream assimilation, in terms of population equivalent, PE,

F = streamflow, in mgd,

b_2 = assimilation ratio, PE per mgd,

S = amount of storage, ac ft,

I = initial minimum streamflow in absence of storage, in mgd,

C_S = annual capital and operating cost of storage,

a_3 = storage required to make initial flow available at all times, ac ft,

b_3 = the marginal amount of storage required to increase streamflow by 1 mgd, ac ft per mgd,

a_4 = fixed cost of storage, in dollars, and

b_4 = marginal cost of increments of storage capacity, dollars per ac ft.

The cost relation for water quality improvement (waste reduction) by low-flow augmentation was obtained by combining Eqs. 85a, 85b, and 85c to give

$$Q_S = b_2 I \frac{b_2 a_4}{b_3 b_4} - \frac{b_2 a_3}{b_3} + \frac{b_2}{b_3 b_4} C_S \qquad (86)$$

Equations 84 and 86 were combined to provide the simplified mathematical model for an isoquality line, since $Q_T + Q_S = N$.

$$C_T = a_1 N - b_1 b_2 I + \frac{b_1 b_2 a_4}{b_3 b_4} + \frac{b_1 b_2 a_3}{b_3} - \frac{b_1 b_2}{b_3 b_4} C_S \qquad (87)$$

In a given problem, values of N and I are established, and all terms in Eq. 87 except the last term become constants. The slope of the isoquality line ($\partial C_T/\partial C_S$) is given by $- b_1 b_2/b_3 b_4$. If this term is less than unity, as indicated by Bramhall and Mills, then the isoquality line intersects the lowest isocost line at the vertical axis, showing that additional waste water treatment is the least-cost policy compared to low-flow augmentation. If the slope term is more than unity, then the solution shifts to the horizontal axis and low-flow augmentation becomes the optimum policy. This edge solution arises because of the linear form of Eq. 87.

In a study of the stream basins in western Maryland, Bramhall and Mills found that their economic analysis gave little justification for low-flow augmentation. Therefore, additional analysis was made to determine the levels of marginal costs expressed as coefficients b_1, b_2, b_3, and b_4 that would be required to achieve a slope of - 1.0, a position which would permit free substitution of the two alternatives (the isoquality line would be superimposed on the isocost line), assuming Eq. 87 applies. It was concluded that in the river basin studied (Potomac River tributaries) that the <u>optimum waste reduction process</u>

combination would include a high level of waste water treatment and relatively little low-flow augmentation. However, they admitted difficulty in separating the costs of reservoir storage allocated to water quality improvement from other multipurpose uses, since the conservation storage allocation served several interrelated uses.

D. More Complex Systems Analysis Using Linear Programming

1. General concepts

Mathematical programming has become a familiar technique of optimization, having been developed within the context of operations research. McKean (1958) described the historical development of operations research and its growth into systems analysis for the solution of complex problems. Linear programming has been used in several water quality studies at the river basin level.

In mathematical terms, linear programming can be defined (Dano, 1960, p. 2) as

> ...the problem of finding a maximum (or minimum) of a linear function, subject to linear side conditions and to the requirement that the variables should be non-negative. The side conditions form a system of linear equations (or inequalities). When the number of variables exceeds the number of equations the system will in general have an infinite number of solutions, of which those involving negative values of one or more variables are discarded, and the problem is to find the optimal solution, i.e., the one that yields the largest (or smallest) value of the linear function which is used as a criterion of optimality.

In water quality studies of river basins, application of linear programming provides a method for obtaining a given level of quality at least cost, thus implying the minimization of a linear function of system inputs. The nonnegative stipulation is designed to assure economically meaningful solutions. In terms of cost minimization, the system of linear inequalities becomes the system of constraints within which a solution is desired.

In general, the constraints can be expressed in the form of m inequalities (or equations) for m variables in the form

$$
\begin{aligned}
&a_{11}x_1 + a_{12}x_2 + \ldots\ldots a_{1j}x_j + \ldots\ldots a_{1n}x_n = b_1 \\
&a_{21}x_1 + a_{22}x_2 + \ldots\ldots a_{2j}x_j + \ldots\ldots a_{2n}x_n = b_2 \\
&\ldots\ldots\ldots\ldots \\
&a_{i1}x_1 + a_{i2}x_2 + \ldots\ldots a_{ij}x_j + \ldots\ldots a_{in}x_n = b_i \\
&a_{m1}x_1 + a_{m2}x_2 + \ldots\ldots a_{mj}x_j + \ldots\ldots a_{mn}x_m = b_n
\end{aligned}
\qquad (88a)
$$

The nonnegativity requirements impose a set of sign restrictions for the variables

$$x_j \geq 0, \qquad j = 1, 2, \ldots\ldots n \qquad (88b)$$

and it is desired to obtain a set of x_j values which maximize (or minimize) the linear objective function

$$Z = c_1x_1 + c_2x_2 + \ldots\ldots + c_jx_j + \ldots.\ c_nx_n \qquad (88c)$$

The quantities a_{ij}, b_i, and c_j are assumed to be known constants or coefficients representing activities or processes. The same equations hold for minimization of a linear function (Dano, 1960, p. 5). When inequalities arise in the side conditions, slack variables are introduced, as x_i' variables, to account for the difference between the right and left sides of each inequality. Because cost minimization is of interest in this study, the minimization of Z when inequalities occur takes precedence over the maximization version. Thus, the linear inequalities (side conditions) of the problem

$$a_{i1}x_1 + a_{i2}x_2 + \ldots\ldots.. + a_{in}x_n \geq b_i \qquad (i = 1, 2, \ldots, m)$$

$$x_j \geq 0 \qquad (j = 1, 2, \ldots, n)$$

$$c_1x_1 + c_2x_2 + \ldots\ldots.. + c_nx_n = Z = \text{minimum}$$

may be transformed into equations by subtracting nonnegative slack variables on the left side of all inequalities:

$$a_{i1}x_1 + a_{i2}x_2 + \ldots\ldots.. + a_{in}x_n - x_i' = b_i \qquad (i = 1, 2, .., m) \qquad (88d)$$

The transformed problem then includes n "structural variables" of the type x_j and m "slack variables" of the type x_j'. The latter have zero coefficients when included in the linear function Z ($c_j' = 0$), and they must be nonnegative also or the inequalities would become reversed in sign.

2. Methods of obtaining solutions

Any set of nonnegative numbers, x_j, which satisfy the objective function is a feasible solution, and the one which yields a maximum (or minimum) value is called the optimal solution (Dano, 1960). If more than one optimal solution exists, it is called an alternative optima, and implies that the activities or processes can be combined in more than one way to maximize or minimize the objective function.

Because the problem with inequalities included now consists of (n + m) variables and with m equations for the side conditions, a direct solution is not possible nor are other traditional methods capable of solving it (Dano, 1960, p. 6). An iterative process is therefore suggested as a means of testing solutions. The fundamental theorem of linear programming states

> If a linear programming problem with m side conditions has an optimal solution, then there exists such a solution in which at most m of the variables are $\neq 0$ (or conversely, at least n - m of the variables will equal zero).

Additional development of the concepts and theory of linear programming has shown the general nature of the region in which solutions may be found. As summarized by Dano (1960)

> ...the optimal solution can appear as a "corner maximum"; the geometric picture of the set of feasible solutions is a convex area and the optimal solution is one of the "extreme points" ("corners") of the area — except for the special case in which any point on the segment is optimal, including the two extreme points....

Convexity in a set of points was defined as meaning that the segment joining any two points in the set is also in the set. In linear programming, if the maximum or minimum value of the objective function Z is finite, then at least one corner of the region of feasible solution is an optimal solution.

The fundamental theorem of linear programming, as stated previously, showed that with m side equations and (including slack variables) n + m variables, no more than m of these n + m variables would be included in the optimal solution. Knowing this, iterative techniques can be developed which provide a means of obtaining an optimal solution, if such an optimal solution exists. These iterative techniques have been classified as "algorithms;" an algorithm is a rule of procedure for solving a mathematical problem that frequently involves repetition of an operation (Merriam, 1967).

If there are not too many values of m and n, then a simple algorithm exists for seeking a solution (Dano, 1960). Set n - m of the n variables (n + m variables with the slack ones included) equal to zero in the m linear equations and solve for the remaining m variables (structural and slack variables being treated alike). There are $\binom{n}{m}$ equation systems to be solved. As noted by Dano (1960, p. 10), the solution which includes the remaining m variables as "basic variables" is called the "basic solution." The procedure then involves additional testing,

> ...those that yield solutions involving negative values for one or more variables are discarded — in many cases this can be done without actually having to solve them because inspection shows that the solutions will not be feasible — and the optimal solution will be that basic feasible solution which gives the largest value to the preference (objective) function.

For larger values of m and n this algorithm is impracticable. The procedure most frequently used is the "Simplex Method" attributed to Dantzig (Dano, 1960, pp. 11-14). Essentially, this procedure involves first selecting an arbitrary basic feasible solution as a starting point (as described above) and next determining by examination whether a better solution can be obtained by shifting to a second basis, and so forth, until a basic solution is attained which maximizes (or minimizes) the objective function. The simplex coefficients that arise in the basic feasible solution provide the information for concluding whether an optimal solution has appeared, or which new variables should be used as a new basis. Thus, m variables are selected as an initial basis, all other x_j's are treated as variables in solving the side equations for the m variables, and finally the objective function Z is expressed in terms of the nonbasic variables through substitution. The coefficients in the transformed objective function become the simplex coefficients. The simplex procedure provides an algorithm that is a systematic method of exploring the set of basic feasible solutions without having to compute every one of them. A sufficient condition for a basic feasible solution to be optimal is nonnegativity of the simplex coefficients in the transformed objective function, or nonpositivity for cost minimization problems.

Additional problems of degeneracy, homogeneity and additivity in the linear side equations, nonexistence of an optimal solution, alternate optima and techniques for tabulation of the procedures in a simplex table must be considered in practical application of the linear programming method using simplex techniques (Heady and Candler, 1958; Dano, 1960).

3. The dual problem

Each linear programming model has the inherent property of forming pairs of symmetrical problems. As noted by Dano (1960)

> To any maximization problem corresponds a minimization problem involving the same data, and there is a close correspondence between their optimal solutions. The two problems are said to be "duals" of each other.

In economics, the physical coefficients used in allocating resources and pricing concepts are both included in the general problem of determining an optimum policy. The dual concept of linear programming permits both the allocation phase and the pricing aspect to be solved. The primal problem was formulated in Eqs. 88a to 88d. For the dual problem, unit price variables are introduced and a new objective function is constructed. The new variables are

$$w_1, w_2, w_3, \ldots\ldots\ldots\ldots\ldots\ldots, w_i, \ldots\ldots\ldots\ldots\ w_m$$

with each being a variable for the m constraints of the primal problem. The coefficients in the objective function of the dual problem are the constant terms of the right-hand side of the primal inequalities (or constraints), of Eqs. 88a to 88d. This provides for the objective function of the dual problem

$$Z' = b_1w_1 + b_2w_2 + \ldots\ldots + b_iw_i + \ldots\ldots + b_mw_m \tag{89a}$$

which is formed as a sum of the cross products of the unit price variables with the constants on the right-hand side of the side equations. The dual inequalities take the form (for the cost minimization problem)

$$\begin{aligned}
&a_{11}w_1 + a_{21}w_2 + \ldots\ldots + a_{j1}w_j + \ldots\ldots + a_{m1}w_m \geq c_1 \\
&a_{12}w_1 + a_{22}w_2 + \ldots\ldots + a_{j2}w_j + \ldots\ldots + a_{m2}w_2 \geq c_2 \\
&\ldots\ldots\ldots \\
&a_{1i}w_i + a_{2i}w_2 + \ldots\ldots + a_{ji}w_j + \ldots\ldots + a_{mi}w_i \geq c_i \\
&\ldots\ldots\ldots \\
&a_{1n}w_n + a_{2n}w_n + \ldots\ldots + a_{jn}w_j + \ldots\ldots + a_{mn}w_n \leq c_n
\end{aligned} \tag{89b}$$

The dual problem is solved by finding nonnegative values for the unit price variable, w_j's, where

$$w_j \geq 0, \qquad j = 1, 2, \ldots\ldots, r. \qquad (89c)$$

so that the linear objective function Z' can be minimized. Slack variables can be introduced into Eq. 89b to permit expressing the side conditions of the dual problem as equations. As noted by Dano (1960, p. 90)

> ...the right hand terms of one problem become the coefficients in the preference function of the other; furthermore whereas the first is concerned with minimizing a linear function subject to inequalities of the type $\geq$, the second is a maximization problem involving inequalities of the reverse type.

The duality theorem for the general case is expressed as

> (i) the maximum value of Z is equal to the minimum value of Z', and
>
> (ii) in the optimal basic solutions, the value of any variable in the first (primal) is numerically equal to the simplex coefficient of the corresponding variable in the second (dual) and vice versa.

In economic terms, the x_j's are values of quantities of constituents in a physical system or process. The dual variables w_j's have the dimension of prices per unit of the constituents, and reflect a valuation of the system outputs based upon marginal cost considerations. This set of imputed prices are referred to as "shadow prices" being internal to the problem and not in any way reflecting market prices. With this internal price structure, the total imputed value of the quantities of outputs produced by one unit of each input can be calculated, and compared with the actual cost to obtain a criterion for determining which physical constituents, the x_j's, should be used to satisfy the objective function. As concluded by Dano (1960, p. 93)

> ...thus the shadow prices, as determined by solving the dual problem, provide a criterion of optimality which is equivalent to determining the optimal combination of x_j's directly from the first (primal) problem. In other words, the problem of optimal allocation can be formulated and solved alternately in terms of prices or quantities. This is the economic content of the duality property of the mathematical model.........if the optimal basis in one of the two problems is known, then the corresponding variables in the other problem will be zero in the optimal solution, so that in the latter the optimal basis will consist of the remaining variables.

In terms of matrix algebra, the coefficients in Eq. 89b are obtained by transposing the matrix of coefficients given in Eq. 88a. In vector notation, the primal problem has the form (for cost minimization)

$$\bar{A}\,\bar{x} \geq \bar{b} \qquad \bar{x} \geq 0 \qquad \text{MIN } Z = \bar{c}\,\bar{x}$$

and the dual problem becomes

$$\bar{A}'\,\bar{w} \leq \bar{c}' \qquad \bar{w} \geq 0 \qquad \text{MAX } Z' = \bar{b}'\,\bar{w}$$

where the transposed matrix is given by the primed notation.

4. Application of linear programming in water quality studies

For stream water quality models, using DO as the major parameter of water quality, $\bar{A} = a_{ij}$ is an m by n matrix of coefficients reflecting the stream's assimilative capacity. Each x_j in $\bar{x}$ is a measure of waste treatment efficiency or proportion of the raw waste load which can be discharged to the stream, the unknown for which a solution is desired. This means that $\bar{A}\,\bar{x}$ is the vector of DO changes resulting from a point waste load (with some treatment efficiency applied to the point raw waste load expressed in terms of BOD). Equations 79a and 79b are used in forming the vector $\bar{A}\,\bar{x}$, with modifications to fit the assumed field conditions. Regulatory practices require (especially for uniform treatment standards) that $x \geq 0$, and a minimum of primary treatment would immediately imply 30 to 35% removal of the BOD waste load. The minimum DO levels desired (above total depletion) require that $\overline{b} \geq 0$. Complete removal or elimination of a waste load through advanced treatment methods places an upper bound on the x_j's in x, since 100% removal is not possible. If x is expressed as treatment efficiency, then $0 \leq x_j \leq U_j$ where $\overline{U}$ is the n vector of upper bounds. The objective function is to minimize $\overline{Z} = \overline{c}\ \overline{x}$, $\overline{c}$ being a row vector of c_j unit costs which must be evaluated in terms of treatment plant efficiency and realistic cost estimates for construction, operation, and maintenance. Both Frankel (1965a) and Deininger (1965) have developed relationships for these unit cost factors based upon published cost data. Sobel (1965) has elaborated additionally upon techniques established by Dantzig (1963) for applying linear programming to water quality management problems in complex situations, and outlines the general procedures for application to actual stream conditions.

Graves and Hatfield (1969) noted that in any given linear programming problem, three possibilities exist. There (1) exists a finite value for the objective function and an optimal solution is obtained, or (2) the constraints for the primal problem are inconsistent, and the constraints for the dual problem are either inconsistent or the dual extremal function is unbounded, or (3) the primal extremal function is unbounded and the constraints for the dual problem are inconsistent. An advanced level algorithm is also presented by these authors, and used in studies of estuarine water quality.

E. Application of Economic Models to Stream Water Quality Problems

1. Benefit-cost studies

Studies of water quality improvement programs for streams have varied from the very simple to the complex stream-estuary environment. The work of Frankel (1965a, 1965b) in developing an engineering-economic model for a stream reach in which an upstream polluter affected a downstream water treatment plant illustrated the use of a complex physical mathematical model with straightforward application of engineering economics. Substantial cost information data collated for both waste treatment plants and water treatment processes, and may be of benefit in this study. The benefit-cost analysis presented by Bramer (1966) also follows along traditional methods of engineering economic evaluation. Susag et al. (1966) developed an engineering-economic model for evaluating the worth of mechanical surface reaeration of receiving streams and applied it to a reach of the Mississippi River downstream of St. Paul, Minnesota. An economic comparison was made between the costs of additional treatment and mechanical surface aeration. Analysis of the duration curve indicated that additional treatment above the secondary treatment level would be required 7% of the time on an average annual basis. Standard economic evaluation of the additional waste treatment was made, and results compared to the mathematical model results of surface aeration. A 2 mg/1 minimum DO level was used as the water quality criterion for comparison. The total annual costs (amortized fixed charges and annual operation and maintenance) of the mechanical surface aeration alternative ranged from 25 to 50% of those for additional waste water treatment.

Other investigators, in addition to Frankel (1965a, 1965b), have analyzed plant operation and cost data in efforts to correlate stream water quality to increased costs of treatment for water supplies. Young et al. (1965) made a statistical correlation of water quality parameters (BOD, COD, hardness, color, DO deficit, TDS, Cl demand, and turbidity) with increased costs of water treatment. Data were obtained by questionnaire from municipalities in the eastern U.S.A. A definite correlation existed for additional chemical costs, with a positive relation being obtained for the selected parameters. Additional study was recommended prior to adoption of the results for general use.

Baxter (1966) also reported on initial studies at Philadelphia that were being made to determine the effect of water quality on the treatment costs for municipal water use. Turbidity, dissolved oxygen, and bacterial levels (coliform organisms) were the major parameters evaluated, although temperature was noted to be related to treatment costs as well as to the DO level, thus overshadowing the effect of DO. The evaluation of the economics of using pumped storage as a means of enhancing water quality was made by Velz et al. (1966). Excess flow during high-flow periods would be pumped to off-stream storage reservoirs for low-flow augmentation during periods of deficient streamflow. When the pumped storage facility was utilized as a hydroelectric source of energy on the release side, and incorporated into basin electric energy alternatives as well as water quality alternatives, then substantial cost savings for the entire system were realized.

2. Linear programming studies

Application of linear programming to water resources problems including water quality was fostered by the Harvard water studies group (Maass, et al., 1962). Thomann (1963, 1965), Sobel (1965), and Johnson (1967) have reported on application of linear programming models to water quality problems in estuaries, with partial application indicated for normal stream behavior. Deininger (1965) developed a linear programming model for a hypothetical stream system, using for physical coefficients a form of the waste assimilative equations, Eqs. 79 and 80. Improved algorithms for solving the complex system were introduced. Davis (1966) applied similar systems techniques in a study of alternatives in meeting a 5 mg/l DO level in the Potomac River basin, a value previously adopted in studies of low-flow augmentation by reservoir storage. The results showed that stream aeration was far less expensive than either low-flow augmentation or other more advanced tertiary treatment methods. However, low-flow augmentation was less expensive as an alternative than the advanced or tertiary treatment methods.

A review of the status of systems analysis in solving water resources problems was reported recently as a proceedings summary (Deininger et al., 1968). Advanced methods of programming including algorithms for linear, dynamic, parametric and stochastic programming were included.

F. Summary

Many of the strategies of these more complex mathematical models have been oriented towards the concept of effluent charges, an idea first introduced and expanded upon by Kneese (1962, 1964, 1966, 1967). Various methods of allocating waste discharges economically in a complex river basin environment have been considered. The four major methods were listed by Johnson (1967):

> 1. Uniform Treatment (UT). This scheme may be considered as representative of conventional water pollution control programs. All dischargers must remove a specified equal proportion of their respective waste loads before discharging to the water body.
>
> 2. Least Cost (LC). Allowable waste discharges are allocated on the basis of marginal costs of removal in such a manner as to minimize the total cost of meeting a dissolved oxygen goal.
>
> 3. Single Effluent Charge (SECH). A uniform price per unit of oxygen-demanding material discharged to the estuary is applied to each waste source.
>
> 4. Zone Effluent Charge (ZECH). An effluent charge varying with the geographical location of the waste discharger is levied on each unit of oxygen-demanding material discharged.

Computational models using linear programming have been developed to assist in solving for optimal solutions for each of these circumstances (Thomann, 1963; Sobel, 1965; Thomann, 1965; Thomann and Sobel, 1965; Johnson, 1967). Revelle et al. (1968) developed a linear programming model for achieving specified water quality objectives at minimum cost and applied it to the Willamette River in Oregon. Results were compared to the solution of Liebmann and Lynn (1966) who used a dynamic programming model. Although a few plants in the river reach studied would be required to achieve different efficiencies under the two methods of study, the overall results were the same. All of these studies have shown that the least cost (LC) method consistently provides a lower total cost of reducing pollution in comparison to uniform treatment (UT). More treatment is usually required at the points of large waste discharge and less at points of small quantities of waste effluent. Scale economies and the substantial effect of large loads on the assimilative capacity of the stream appear to be the predominant factors tending to give this result. Johnson (1967) concluded that cost of waste treatment induced by a charge level (SECH) will approach the least costly treatment plan, for improving water quality in a stream.

The engineering-economic models permit the economic dimension to be injected into the analysis of water quality improvement in a stream basin. This provides not only a concept of optimal or near-optimal solutions for a given situation, but can provide through the dual problem, for instance, a concept of the economic sensitivity of the results. Additional information is then made available to the decision maker concerning the implications and consequences of policy actions.

A final aspect can and should be included. A recent study concerning public attitudes toward water pollution has been reported (Frederickson and Magnas, 1968). A carefully controlled opinion poll was made in the Syracuse, New York, metropolitan area that permitted the respondents to assign their relative importance associated with alternative areas of public policy. Using two separate methods of evaluating attitudes toward the need for water pollution control, they determined that education and police protection were considered to be first and second in priority or preference, with water pollution third. Other categories receiving less public support, percentage wise, were employment, adequate water, welfare, street maintenance, housing, traffic tieups, and parks and recreation., It was also evident that people in the lower socioeconomic profile who live in or near the central city placed less importance on water pollution than did the more affluent members of society. Thus it was concluded that water pollution control emerged as a middle-class issue, and with this group having a predominant influence in the legislative and policy-making circles, continued support was foreseen.

VII. SUMMARY OF BASIC CONCEPTS

The historical review has revealed the reasons for the existence of water pollution as man has intensified his use of the natural environment. The stream system serves as a convenient and useful means of waste disposal for the many residues of a modern industrial society. Interactions and conflicts among those individuals and groups making beneficial use of the water quality as well as quantity have brought the problem of water pollution to the forefront. Those beneficial uses vying for quality and quantity include water supply (domestic, municipal, industrial, and agricultural), power production, navigation, recreation, fish and wildlife propagation, and water quality control functioning within the context of disposal of treated (or untreated) wastes.

The meaning of water pollution, related terminology, and objectives of pollution control measures have been explored and clarified. Pollution must be expressed in terms of the beneficial uses which may be affected thereby. In terms of properties influencing water quality, four groups have been identified. These include those substances that are (1) not permissible, (2) undesirable or objectionable, (3) permissible but not necessarily desirable, and (4) desirable. Within this framework, pollution has been defined as

> ...an undesirable change in the physical, chemical, or biological characteristics of our air, land, and water that may or will harmfully affect human life or that of other desirable species, our industrial processes, living conditions, and cultural assets; or that may or will waste or deteriorate our raw material resources.

The three major aspects of the water pollution problem — physical, economic (including social), and institutional (including the management phase) — have been discussed as they relate to water quality improvement. The roles of the various levels of government and of the several educational and research disciplines existing within society have been reviewed. There is an urgent need for coordinated interdisciplinary efforts if meaningful water quality standards are to be established and if real improvements in water quality are to be realized.

The implementation at the national level of requirements for water quality standards for surface waters has placed the initial burden on the states to establish and enforce acceptable water quality standards and related criteria. Both stream standards and effluent standards must be included in a comprehensive state-wide program for maintaining and enhancing water quality. As discussed herein, stream standards designate the beneficial uses of water that will be protected. The effluent standard becomes necessary in the operation and control phase of water quality improvement programs, especially in stream reaches where multiple discharges of effluents is a reality, and identification of the waste from a specific outfall discharge is impossible.

The four freedoms of the Ohio River Valley Water Sanitation Commission (ORSANCO) provide additional guidance in the establishment of minimum conditions or levels of water quality in surface waters. These basic concepts, if enforced, assure a level of water quality that is free from objectionable, unsightly, and deleterious pollutants. This will alleviate obvious pollution, nuisance conditions, and toxic or otherwise harmful effects.

The important categories of potential pollutants were identified as the oxygen demanding wastes, infectious agents, plant nutrients, organic chemical compounds, conservative mineral and chemical substances, sediments, radioactive substances and heat. Related water quality parameters for each have been identified. These parameters permit water quality to be expressed in quantitative terms. Limiting values for these parameters have been tabulated and summarized for future reference. However, much emphasis has been placed at the national level on the fact that the response of the environment to man's activities has not yet been studied and evaluated sufficiently to permit accurate forecasting of the fate of pollutants in the natural environment. More detailed knowledge of the magnitude, effect, and behavior of effluents discharged into specific stream systems is needed.

The importance was discussed of obtaining an adequate mathematical expression of the response of the stream environment as it receives treatment plant effluents and other wastes. Simulation of existing water quality levels can be used to test the adequacy of a given mathematical model. Forecasts of future water quality levels can then be made for management purposes. The mathematical models available for use in water quality studies have been reviewed and summarized. The original formulation by Streeter and Phelps included only two water quality parameters, the carbonaceous organic wastes and atmospheric reaeration of the dissolved oxygen resources. Additional factors that must be included today are the influence of algae, nitrification of ammonia, bank load or boundary contributions of organic wastes, and sludge deposits if raw sewage or large amounts of settleable solids are present.

Several techniques have been presented for accounting for these additional factors.

Economic considerations were the concluding items of this review. Comparison of economic alternatives was found to provide a framework within which more reliable decisions may be forthcoming concerning political programs. Consequences of alternatives can be explored through the economic dimension. Both loss-avoidance benefits and other direct economic impacts have been defined, and it was noted that recreation and esthetics are activities for which economic evaluation is not easily accomplished. Benefit and cost concepts as applied to water quality control were reviewed. Studies of benefits and costs of water quality improvement programs have been made for several case studies, illustrating both the principles of economics and the marginal value of increased water quality control measures in many instances, both real and hypothetical. Additional concepts of cost minimization and linear programming have been outlined for studying more complex water quality problems in which several interactions may occur between two or more water uses. Eleven specific physical methods of achieving water pollution control have been listed. These become a technical base for economic analysis of alternative methods for reaching a desired objective. The interdisciplinary study method encouraged herein provides an opportunity for studying and evaluating the worth of water quality improvement programs, and the degree to which water quality of surface waters can be enhanced through on-going programs which have a severe budget constraint.

This extensive review of the water pollution problem sets the stage for the specific and detailed studies of water pollution in Iowa. The case study of the Skunk River at Ames, Iowa, will involve many of the concepts and fundamental principles outlined herein. These studies will be presented in Vol. II.

PHYSICAL AND ECONOMIC FACTORS ASSOCIATED WITH THE ESTABLISHMENT OF STREAM WATER QUALITY STANDARDS

by

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VOLUME II of III

A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Sanitary Engineering

Approved:

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1969

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A STUDY IN THREE VOLUMES

PREFACE

The stream system in a river basin is an integral part of man's total environment. Its natural function is to return water to the ocean, the ultimate sink for all of the earth's residues as well as being the basic source of atmospheric moisture. The stream system serves also as a natural habitat for various flora and fauna which contribute to a healthy, productive aquatic environment. Man's activities in the twentieth century period of industrialization have accelerated the degradation of the water environment. Serious conflicts related to water quality have arisen among the groups making beneficial use of the surface water resource. Concern at all levels of government has resulted in increased attention and action directed toward the solution of water pollution problems.

Recent research in water quality has been replete in all three dimensions of the water quality framework — the technical, the economic and the institutional. Problem areas such as public health, resources use, technical innovations, economic alternatives, social aspects, and political-institutional-management relationships have been identified and studied through research endeavors. One of the principal objectives of current research is the development of methods of obtaining an optimal level of water quality in a stream commensurate with man's desired uses and the relevant economic constraints. A corollary objective

is determining the most economical solution for treating a region's wastes to obtain a desired minimum level of stream water quality, allocating specific treatment plant efficiencies among the several water use groups competing for the convenience of the stream's water conveyance mechanism.

In a study confined within a single dimension of the threefold technical-economic-institutional framework, it is likely that concepts and data from other dimensions are lacking. This frequently results in the introduction of over-simplifying assumptions. A comprehensive study of methods for achieving selected water quality objectives should include the necessary elements of all three dimensions. Several case studies of selected river basins have been made recently to illustrate the application of newer methods of technical and economic analyses. However, no comprehensive studies encompassing these three dimensions have been made for Iowa, and the status of the interrelated elements has not been explored fully in this region.

This treatise is devoted also to the water pollution problem, with specific emphasis on problems in Iowa. Adoption and enforcement of the Iowa water quality standards for surface waters have as their objective the enhancement of water quality. The degree to which this enhancement can be realized and the related economic impact of such enhancement has received major attention in this study. The purposes for which this detailed study was conducted include

- to explore in a broad manner the underlying principles of each of the three dimensions (technical-economic-institutional) as they relate to stream water quality standards in Iowa,

- to list and evaluate the parameters that will influence water quality in Iowa streams including those that are of greatest concern in the establishment and enforcement of stream standards,
- to review and evaluate the hydrologic characteristics of Iowa streams as these characteristics become determinants in the water quality enhancement program,
- to identify the nature and characteristics of municipal effluents discharged to the stream environment,
- to study the response of a typical central Iowa stream as it receives waste discharges from a municipal water pollution control plant, and
- to determine for an urban area the economic importance of water pollution control and stream water quality enhancement, and the related impact of water quality standards on expenditures for a stream improvement program.

This treatise on water quality is divided into three parts. Vol. I is devoted to the initial two purposes listed above, and includes (1) a historical review of the water pollution problem, (2) identification and discussion of the potential effects of pollutants, and (3) application concepts for establishment and enforcement of water quality standards. Vol. II is devoted to a detailed study of Iowa stream conditions as outlined in the last four of the six purposes listed above. These specific studies include (1) a general study of Iowa stream water quality problems and availability of data, (2) the relationship of hydrologic characteristics and assimilative capacities of Iowa streams, and (3) a comprehensive technical-economic case study of the Skunk River at Ames, Iowa. Vol. III consists of the appendices for the detailed studies, and includes (1) basic data for the study, (2) selected hydrologic and water quality study information and results, (3) tabulated results of the water quality response model for the study area, and

(4) other supporting data.

It was the goal of this research endeavor to compile in one document the pertinent information concerning water quality in surface waters, and to provide through the comprehensive case study a means of directing future research efforts and activities. These are outlined in the concluding section of Vol. II. The case study permitted observing and measuring the response of the stream environment to man's water quality inputs, provided an opportunity for concentrated research and application methods, and hopefully produced meaningful results for a river basin in central Iowa where a rapidly expanding urban area is located.

VIII. OBJECTIVES AND SCOPE OF THE DETAILED WATER QUALITY STUDIES

A. General

Vol. II of this water quality treatise, beginning with Chapter VIII, is devoted to the detailed water quality studies conducted in the second phase of the research program. These studies include a survey of state-wide stream water quality problems, hydrologic relationships that influence the levels of water quality capable of being attained, and a comprehensive case study of the Skunk River at Ames, Iowa. Specific attention was directed to problems associated with municipal waste sources, treatment, and the effect of point sinks of effluent discharge on the receiving streams. This selection was made because of the emphasis placed on municipal waste treatment, including related industrial waste contributions, in the initial establishment of Iowa stream water quality standards.

In this section, a brief review will be made of the availability of hydrologic and water quality data in Iowa, special studies that have been conducted, and established waste treatment standards and stream water quality criteria that have a bearing on the research described in Vol. II. The types of physical and economic studies that were conducted to provide additional data and permit evaluation of water quality relationships for Iowa streams will also be outlined. Methodology for the proposed case study of the Skunk River at Ames, Iowa, will be included. The Skunk River basin is illustrated in Fig. 9.

Fig. 9. The Skunk River basin (after Iowa Natural Resources Council, 1957).

B. Availability of Hydrologic and Water Quality Data

1. Water quality data

The initial appraisal of the availability of water quality data for Iowa streams revealed a dearth of information for all of the intrastate or interior streams. The 1960 status report of the surface water quality monitoring schedule (Schliekelman, 1965) indicated that the program, initiated in 1955, provided for monthly, quarterly, and in some cases semiannual sampling at 29 selected locations. Laboratory determinations of selected water quality parameters were made following the field collection of samples. Fifteen of the 29 sampling points pertained to surface water sources, both lake and stream. A summary of this early monitoring schedule is provided in Table 11.

Two sampling stations in the Skunk River basin, Ames and Oskaloosa, were included in the report as points for quarterly sampling. The single station at Ames was located a few miles upstream of the city. Water quality determinations included the minerals listed in Table 11. The Iowa State Department of Health has been involved in one additional comprehensive study related to water quality. This was a study on the Cedar River directed toward the identification of biological precursors of taste and odor compounds (Morris, 1967; Iowa Water Pollution Control Commission, 1967).

General information concerning the status of municipal water supply and waste treatment facilities has been published by the Iowa State Department of Health (1964, 1965a). For municipal water supplies obtained from either surface or groundwater sources the published information included types of treatment, source of water, and chemical characteristics of the raw water. For some cities the characteristics of the treated

Table 11. Surface water quality monitoring schedule and status report as of 1960[a]

A. Streams sampled:

Stream or river	Location	Remarks
Des Moines River	Fort Dodge	Quarterly, infrared
	Des Moines	Monthly, infrared, ABS
	Ottumwa	Monthly, infrared, ABS
Raccoon River	Panora	-[b]
	Adel	-[b]
	Des Moines	Monthly, infrared, ABS
Skunk River	Ames	Quarterly, infrared
	Oskaloosa	Quarterly, infrared
Cedar River	Cedar Rapids	Monthly, infrared, ABS
Iowa River	Marshalltown	Quarterly, infrared
	Iowa City	Monthly, infrared, ABS
Nodaway River	Clarinda	-[b]
102 River	Bedford	-[b]
Big Sioux River	Sioux City	-[b]

[a]Source: Schliekelman (1965).

[b]No sampling schedule given, presumed intermittent.

Table 11 (Continued)

B. Determinations made[c]:

Temperature	COD	Iron
Specific conductance	P-total	Mn
Dissolved solids	PO_4-soluble	F
Hardness	Na	Cl
Alkalinity	K	SO_4
Nitrogen compounds	Ca	HCO_3
pH	Mg	Silica

[c]Frequency of determinations — Quarterly: Mineral, COD, nitrogens, solids
— Quarterly: Infrared spectograms on limited stations (1960)
— Monthly: ABS on limited stations (1960)
— Semiannual: Phosphates.

water were also determined. Chemical or mineral characteristics included pH, dissolved solids, total solids, soluble and total iron, silica, alkalinity, hardness, and specific minerals (K, Na, Ca, Mg, Mn, NO_3, F, Cl, SO_4, HCO_3, and CO_3) for the period 1956-1964. The report of sewerage statistics identified all water pollution control plants in the state, the 1960 population of each municipality involved, and types of treatment facilities. The latter included the categories of primary, secondary or other type of BOD and suspended solids removal, and the type of sludge digestion and disposal used. No stream water quality data were listed in this publication.

Special water pollution investigations are made by the Iowa State Department of Health, Division of Public Health Engineering, upon receipt of complaints by private individuals and water conservation interests. Typical of these for interior streams are reports for the Des Moines River at Algona and the Skunk River at Ellsworth (Iowa State Department of Health, 1952, 1965b). At the latter location, a short reach of the Skunk River was examined through a sanitary survey. The community is located about 25 mi upstream of Ames. A turkey processing plant, residences and businesses in the west part of the town were discharging untreated or partially treated wastes to the stream. Data were obtained for two short daily periods (one in February and one in October) in a 6-mi reach of the stream extending downstream to Randall. Data collected in the sanitary survey included temperature, pH, DO, BOD, and bacterial analysis for coliform bacteria (MPN per 100 ml). Streamflow estimates also were made, based on the discharge records of the gaging station near Ames.

2. Reports and data of other agencies

The U.S. Geological Survey (1968) conducts a water quality sampling program for the State of Iowa, in cooperation with the Iowa Geological Survey and other agencies. This provides sediment data primarily, with some temperature data. Mineral analysis of water samples is made at selected sites on the two major border streams, the Mississippi and Missouri Rivers.

Stream stage and discharge data are collected at several locations in the Skunk River basin, as part of the U.S. Geological Survey (1968) program, and data collection and analysis are coordinated with state and local agencies. Data are available for the following stations in the study basin:

	Stream	Location	Drainage area, sq mi	Period of record
1.	Skunk River	Near Ames	315	1920 to 1927 1933 to date
2.	Squaw Creek	At Ames	204	1919 to 1927 1965 to date
3.	Skunk River	Below Squaw Creek	556	1952 to date
4.	Indian Creek	At Mingo	247	1958 to date
5.	Skunk River	At Oskaloosa	1,635	1948 to date
6.	North Skunk River	At Sigourney	730	1945 to date
7.	Skunk River	At Coppock	2,916	1913 to 1944
8.	Skunk River	At Augusta	4,303	1915 to date

Schwob (1958) made a comprehensive study of low-flow characteristics of Iowa streams, using stream data through the year 1956. A base period of 1933-1953 was selected to represent one major drought period and one major wet weather period. Historical low flows were tabulated, duration curve percentage values provided for all stations (having at least 5 yr of record), and the magnitude and frequency of low flows computed for streams with records of 10 yr or more in length. Data obtained at six of the seven gaging stations currently being operated in the Skunk River basin were included in the report, as were data for the one discontinued station. However, only one of the upstream stations (Skunk River near Ames) was included in the group for which low-flow frequencies were evaluated.

The city of Ames, through a water pollution control program initiated in the early 1960's, has obtained and analyzed once-weekly samples from the Skunk River at two locations. The first site is at the stream gaging station located at the confluence of Squaw Creek and Skunk River, about 0.37 mi upstream of the outfall of the Ames water pollution control plant. The second location is downstream of the plant, at either of two county road bridges. The first bridge, located about 1.80 mi downstream of the plant outfall, is located on an unimproved county road. When this road is impassable, samples are obtained at the next downstream bridge site located 2.93 mi downstream of the plant outfall. Dissolved oxygen, biochemical oxygen demand, nitrogen and phosphate determinations are the primary water quality parameters evaluated in this program.

In addition, the city of Ames has collated a fairly detailed and complete record of the operation of the water pollution control plant since its construction in the early 1950's. Most plant sampling has been conducted on a once-weekly basis, with intermittent periods of less frequent sampling. Monthly summaries are made, and the data tabulated in annual reports. The Ames water pollution control plant serves three major users: the municipality, Iowa State University, and the National Animal Disease Laboratory of the U.S. Department of Agriculture. Waste treatment consists of aeration, grit removal, primary settling, secondary treatment using trickling filters, and final settling. Sludge digestion, drying beds, and sludge lagoons are used to dispose of the waste solids. A chlorination contact chamber was constructed near the final settling tanks, but has never been used. The annual summaries have included volumes of waste water for each of the three users, reduction or removal percentages for biochemical oxygen demand (BOD_5), suspended solids (SS), gas and power production, and a plant financial summary. One report on temporal variations in waste characteristics at Ames has been published (Hutchinson and Baumann, 1958).

The weekly sampling program of the city of Ames at two points on the Skunk River has provided an initial indication of (1) the background water quality upstream of the outfall and (2) downstream conditions following discharge of a treated effluent. However, there remains a lack of data concerning spatial and temporal variations in the stream. No time of travel information is available for the Skunk River or other intrastate streams, other than flood crest movements tabulated by the Corps of Engineers. However, the flood data provides no information concerning low-flow conditions.

A general inventory of water resources and water problems in the Skunk River basin was published by the Iowa Natural Resources Council (1957). The status of water use and water pollution control as of 1957 was summarized in this report, including general information regarding basin characteristics, water supply and use, floods and low-flow characteristics, and other aspects of beneficial water uses. No detailed water quality studies of the streams were reported.

Two major water resources studies have been completed by the U.S. Corps of Engineers in the Ames area which include information useful to a water quality study. The first study is included in the published reports recommending authorization and construction of a multipurpose reservoir upstream of Ames on the Skunk River (U.S. Corps of Engineers, 1964; U.S. House of Representatives, 1965). The beneficial uses evaluated in economic analysis of the proposed reservoir were flood control, water supply, recreation, fish and wildlife, and water quality control through low-flow augmentation. This report included selected technical and economic information regarding low-flow augmentation as an alternative to additional waste treatment at Ames.

The second study involved a flood plain information bulletin prepared by the U.S. Corps of Engineers (1966) in cooperation with the city of Ames and Iowa State University. The flood plain maps of the urban area at Ames provide information about flood plain uses, locational features, and additional stream channel information.

Two studies of reservoir yield have been completed at Iowa State University, one of which included the Skunk River at the proposed reservoir site, using discharge data as published by the U.S. Geological Survey (Dougal and Shearman, 1964). The second study was more general and included basic concepts of reservoir storage phenomena, including the evapotranspiration losses which reduce the gross yield concept to an experienced net yield basis (Shearman, 1967). In combination with the published report on low-flow characteristics of Iowa streams by Schwob (1958), these two reports provide a means of developing storage-yield relationships for low-flow augmentation from the proposed Ames Reservoir.

A comprehensive water quality study being conducted at Coralville Reservoir at Iowa City, on the Iowa River, provides some additional data concerning stream water quality data upstream, within, and downstream of a typical midwestern multipurpose reservoir (McDonald, 1967). A similar preimpoundment study was initiated by Iowa State University for the Saylorville Reservoir on the Des Moines River (north of Des Moines and west of Ames about 15 mi) (Baumann and Dougal, 1968;

Baumann, 1969). Both studies are supported by the U.S. Corps of Engineers and interested state agencies to provide additional stream and reservoir water quality data for planning, engineering and economic purposes.

Much less information is available for other communities in the upper Skunk River basin upstream of Colfax (or Oskaloosa), other than the State Health Department bulletins listed previously. Little pollution control plant operational data is gathered by the smaller communities. Many of the treatment plants are old and outdated, or no community facilities are provided at all but with each residence in the smallest communities having an individual waste disposal system.

C. Proposed Criteria for Water Quality Standards in Iowa

In May 1967, the Iowa Water Pollution Control Commission (1967) adopted (as the Iowa surface water quality standards) both surface water quality criteria and an implementation and enforcement plan. These had been formulated after studies, due notice, and hearings had been held throughout the state. The adopted standards were then submitted to the FWPCA under the provisions and procedures of the Water Quality Act of 1965. The present beneficial uses of water recognized and categorized in the proposed standards were: (1) municipal water supply, (2) industrial water supply, (3) agricultural uses, including livestock watering and limited supplemental irrigation, (4) fish propagation and wildlife habitat, and (5) recreation.

The "four freedoms" listed by Cleary (1967) and mentioned in the historical review were adopted with little change by the Iowa Water Pollution Control Commission as basic controlling criteria to assure satisfactory control over obvious pollution. Expressed in qualitative terms, these minimum standards were to be applicable to all surface waters in the state and at all times:

> a. Free from substances attributable to municipal, industrial or other discharges that will settle to form putrescent or otherwise objectionable sludge deposits;
>
> b. Free from floating debris, oil, scum and other floating materials attributable to municipal, industrial or other discharges in amounts sufficient to be unsightly or deleterious;
>
> c. Free from materials attributable to municipal, industrial or other discharges producing color, odor or other conditions in such degree as to be detrimental to legitimate uses of water;
>
> d. Free from substances attributable to municipal, industrial or other discharges in concentrations or combinations which are detrimental to human, animal, industrial, agricultural, recreational, aquatic or other legitimate uses of the water.

To support these four freedoms with a quantitative measure, an effluent standard was adopted that provides for a minimum of primary treatment,

> .... no municipality shall discharge any sewage to the waters of the state without effective removal of floatable and settleable solids as the minimum degree of treatment.

In addition, the proposed standards state that

> ...Treatment less than secondary will not be accepted on low-flow streams unless it can be shown that legitimate uses can be protected with a lesser degree of treatment.
>
> All industries will be required to provide the same degree of treatment or control that is required of

> municipalities on the same reach of stream. This degree of treatment will generally be the equivalent of secondary treatment.....

Because of an admitted lack of data concerning the effect of nutrients, removal of nutrients prior to discharge was not recommended.

Specific water quality criteria were applied to protect the following beneficial uses of water: (1) public water supply (point of withdrawal), (2) aquatic life — warm water area, (3) aquatic life — cold water area, and (4) recreation. General criteria apply to other uses, for all surface waters. The specific criteria which may have the greatest economic implications are those assigned to aquatic life, for both warm water areas and cold water areas (including 1968 revisions):

> (1) Warm water areas. Dissolved oxygen: Not less than 5.0 mg/l during at least 16 hours of any 24-hr period and not less than 4.0 mg/l at any time during the 24-hr period.
> pH: Not less than 6.8 nor above 9.0
> Temperature: Not to exceed in interior streams a 93 deg F maximum temperature nor a maximum 10 deg F increase over background or natural temperature. Heat should not be added to any water in such a manner that the rate of change exceeds 2 deg F per hour.
> Chemical constituents: Ammonia nitrogen (N), not to exceed 2 mg/l (additional criteria for metals group).
>
> (2) Cold water areas. All criteria stated for warm water areas apply to cold water areas except as follows:
> Dissolved oxygen: Not less than 7.0 mg/l during at least 16 hours of any 24-hr period nor less than 5.0 mg/l at any time during the 24-hr period.
> Temperature: Not to exceed a 70 deg F maximum temperature. The rate of change due to added heat shall not exceed 2 deg F per hr with a 5 deg F maximum increase from background temperature.

Numerical criteria for bacteriological limits (using fecal coliforms) were adopted as revisions in 1968 (Iowa Water Pollution Control Comm., 1968):

Public water supply — Numerical bacteriological limits of 2,000 fecal coliforms per 100 ml for public water supply raw water sources will be applicable during low-flow periods when such bacteria can be demonstrated to be attributed to pollution by sewage.

Recreation — Numerical bacteriological limits of 200 fecal coliforms per 100 ml for primary contact recreational waters will be applicable during low-flow periods when such bacteria can be demonstrated to be attributable to pollution by sewage.

The Iowa Water Pollution Control Commission identified and designated the surface waters to be protected with the specific criteria, including those used for public water supplies, recreation and aquatic life areas. The surface waters include natural lakes, impoundments, and rivers. This technique represents a modified classification system, since not every mile of every stream was placed in a classified category. The specific sources of surface public water supply for 20 communities were listed, with either natural lake or stream sources being involved. An additional 19 communities which have impoundments were listed. No communities along the Skunk River were listed in the plan as having a surface water intake, although the city of Oskaloosa can use the Skunk River as a standby source, pumping to a small storage reservoir near the plant (Iowa State Department of Health, 1964). Purportedly, the Mental Health Institute at Mount Pleasant has a surface water intake at the low head dam at Oakland Mills.

All natural and artificial lakes used for recreation and aquatic life habitat were tabulated in the implementation plan, each being classified for that use. Streams, and reaches thereof, suitable for warm water or cold water aquatic habitat or for recreation were classified accordingly. Recreation areas in general were limited to segments of the rivers upstream of low head dams (many of these were for small hydroelectric installations since abandoned), where recreation and fishing have established a new priority of use. Seven future potential multipurpose reservoirs were recognized and listed, each of which will include water recreation, fish and wildlife benefits. These are being planned by the U.S. Corps of Engineers. The various surface waters included in the modified classification system and which are in the Skunk River basin are tabulated in Table 12. It should be noted that the Skunk River upstream of Colfax is not designated or classified as an aquatic habitat at the present time, but this purportedly will change upon construction of the authorized Ames Reservoir (as specified in the implementation and enforcement plan).

The criteria and standards adopted for Iowa streams also recognize the probability concept in minimum low flows. Rather than use the lowest flow of record, a specific low-flow probability was selected. To recognize the variability of Iowa stream flows in both the application of water quality criteria and in economic analysis and evaluation of waste treatment requirements, the 7-day, 10-yr low-flow magnitude and frequency were selected. As stated in the implementation plan,

> ...the minimum weekly flow which occurs once in ten years shall be used as the design parameter to determine the degree of treatment necessary to protect the specific water use. Flow will be based on a statistical analysis of existing flow data, if such data are available. This specific surface water criteria shall be met at all times when the flow exceeds the ten year low flow. When the flow is less, the municipality or industry shall not be held responsible for lower stream quality when their waste effluent is receiving the necessary degree of treatment or control to comply with criteria at the ten year low flow.

Table 12. Designated beneficial use areas for surface waters in the Skunk River basin[a]

	Beneficial use	Source	Location	Remarks
1.	Public surface water supplies	Lake or stream supply		None listed for Skunk River basin
		Impoundments	Fairfield Montezuma	
2.	Aquatic life — warm water areas, streams and rivers	Skunk River		From Mississippi River to confluence of North Skunk River
		North Skunk River		Confluence to Highway No. 92
		(South) Skunk River		From North Skunk River to Colfax
3.	Natural lakes, recreation and aquatic life	Little Wall Lake	Hamilton County	273 acres surface area
4.	Artificial lakes, recreation and aquatic life	Lake Geode	Des Moines and Henry Counties	205 acres
		Rock Creek Lake	Jasper County	640 acres
		Lake Keomah	Mahaska County	82 acres
		Lake Darling	Washington County	302 acres

[a]Source: Iowa Water Pollution Control Commission (1967).

Table 12 (Continued)

Beneficial use	Source	Location	Remarks
5. Aquatic life use, cold water areas			None listed for the Skunk River basin
6. Designated recreation areas on Iowa streams	Skunk River	Oakland Mills, Henry County	Pool above low head dam
7. Proposed recreation areas at future multipurpose	Skunk River	Ames, Story County	Proposed Ames Reservoir, authorized stage
reservoir sites	Squaw Creek	Ames, Story County	Proposed Gilbert Reservoir, planning stage

Because certain conservation interests had expressed a desire at public hearings to have an even higher frequency level (or conversely, a lower value of discharge) attached to the proposed criteria, a brief preliminary report on initial studies of hydrologic characteristics of Iowa streams was forwarded to the Commission to show that considerable variation existed in the low-flow characteristics of the interior streams (Dougal, 1966). This information was used subsequently by the Commission in preparing the implementation plan, and the 7-day, 10-yr value was adopted.

All of the criteria which have been listed become constraints in economic evaluation of stream water quality as influenced by discharge of effluents into Iowa streams. In cost minimization studies, the economic implications of varying these criteria can be evaluated, either by relaxing them or by making them more stringent. Equally as important, the optimal (economic) combination of alternative means of meeting the established criteria can be determined. These concepts will be explored in greater detail in the economic phase of the case study.

D. The Enlarged Scope of the Water Quality Studies

The lack of data at the initiation of the research studies made it imperative to review the approach which had originally been proposed (limited primarily to an engineering-economic study). An initial appraisal of the hydrologic, the physical, and the biological characteristics of the study stream was considered necessary if an adequate model was to be constructed with which to evaluate future conditions and requirements. A more extensive approach was then formulated, following the guidelines of Kneese (1962).

According to the conclusions reached by Kneese, if improved waste-disposal planning procedures are to be proposed which take into account "extensive reaches of receiving water and a variety of water-quality control measures," then an efficient means of estimating the reaction of the environment is required. Relevant variables include quantities and characteristics of wastes delivered at specific waste discharge points, stream flow conditions and characteristics, and other hydrologic data. It was further concluded that in the absence of the ability to make deterministic estimates, "the economic and other effects of alternative system designs cannot be adequately predicted and system planning for waste disposal cannot be satisfactorily done."

In elaborating on the form which investigations might take in producing optimum waste disposal system designs, Kneese (1962, p. 87) suggests that the initial step is selection of a prototype basin having a simple hydrology, comparatively few sources and types of waste discharges, relatively few surface water supply intakes, and a limited array of potential treatment and abatement measures. A minimum number of constraints of esthetic, recreation and public health aspects should exist. He noted also that perhaps opportunity for low-flow augmentation should be nonexistent or single-purpose, to avoid complementary and competitive relationships between low-flow augmentation and other beneficial multipurpose uses of water. It was also suggested that an initial objective might be an attempt to minimize the costs associated with treatment and discharge of a given quantity of waste stemming from a specified population and/or industrial process.

There would follow from such data collection and analysis an application of simulation techniques using mathematical programming concepts. Useful results could be obtained once the required objective function was formulated and constraints, physical and economic relationships and other parameters had been determined. From this type of analysis, one could hope to point up the types of information which could improve social decisions in regard to water pollution control programs. A final comment of Kneese was to the effect that with this approach, although not highly idealized to the satisfaction of most economists, such an analysis could provide the basis for additional marginal analysis at a later date.

Kneese (1962), in the concluding section of the book, reemphasized that

> ...several case studies of simple, actual, or realistic prototype areas, displaying a variety of conditions of hydrology, population, industrial distribution, climate, and multipurpose development would be useful in identifying feasible alternatives and evaluating their potential role in pollution abatement planning."

This approach would permit evaluating sensitivity relations, studying alternative methods of waste disposal, etc. Therefore, although a primary objective would be to develop the necessary empirical relationships, a case study would provide an excellent opportunity for the development and testing of optimization procedures.

The approach outlined by Kneese was therefore adopted for the purposes of this research study. The upper Skunk River basin, with particular emphasis on the reach at and downstream of Ames, Iowa, was selected for field investigations. It satisfies Kneese's criteria in several ways:

1. The upper Skunk River basin upstream of Colfax (confluence with Indian Creek) is relatively small in areal extent, 807 sq mi, and hydrologic and other water resource data are available.

2. There are relatively few sources and types of waste discharges, which are scattered in location with little chance for accumulative effects, and there are no listed surface water intakes for beneficial use except for the standby source at Oskaloosa.

3. There is a single large waste discharge point which overshadows all others in the upper basin, that from the city of Ames.

4. The city of Ames is experiencing a rapid population growth, with resultant demand on the water resource and stream environment for waste disposal.

5. All waste water volumes at Ames are treated at one plant, so there are no interferences or complications of multi-plant operation.

6. The authorization of a federal multipurpose reservoir on the Skunk River immediately upstream of Ames provides a small array of alternatives to additional waste treatment, including secondary and tertiary treatment methods and low-flow augmentation.

An additional factor favoring study of the Skunk River basin in the Ames area is the conveniency for field investigations, with Ames being in the approximate center of the upper basin. The willingness and cooperation of the director, superintendent and staff of the water pollution control plant at Ames was another favorable consideration. An opportunity to gain the cooperation of the algology research group in doing corollary work in the field investigation phase was also of benefit.

In final form, the objectives and procedures adopted for detailed studies were as follows:

1. Evaluate, using published streamflow data, the general hydrologic characteristics of Iowa streams as they relate to the problem of establishing and maintaining water quality standards. The regional variations in the ability of Iowa streams to assimilate effluents were the major determinants in this phase. Detailed study was made of the hydrologic low-flow characteristics of the upper Skunk River basin, using the additional data collected since the work of Schwob (1958).

2. Conduct an experimental study of the characteristics of effluents from typical waste treatment processes used in the area of the study. These processes included both activated sludge and trickling filters for secondary treatment, and waste stabilization ponds for smaller communities. The overall effectiveness of plant operation was also a factor included in this phase.

3. Conduct field investigations of selected portions of the Skunk River basin to obtain data from which the behavior of the stream system to effluent discharge may be evaluated. The reach of the Skunk River at and downstream of Ames received the greatest attention, with background information obtained for other areas. The time of travel, assimilative capacity, and fate of pollutants in the stream environment were studied in this phase. Identification was made also of the various sources of pollution in the upper basin.

4. Develop an appropriate and adequate mathematical model which can simulate the observed response of the stream to effluent discharge, and which can be used subsequently to forecast needs and reactions for

future waste loads. Again, primary attention was given to the local problems at Ames.

5. Complete an initial analysis of the economic impact of selected levels of water quality and associated stream water quality standards on the annual cost of waste treatment, using the water quality simulation model and appropriate economic factors. This analysis included an evaluation of future requirements to the year 2000. Past and present municipal expenditures for water pollution control were evaluated to determine the per capita contribution to this municipal need. Comparative data were then evaluated for selected alternatives for treatment requirements for the period 1970-2000.

6. Outline a program for additional research endeavors related to the findings of this study. Additional field studies, extension of reach effects to include the entire basin, and expansion of the mathematical analysis were considerations to be elaborated upon. This approach was directed to additional refinement of optimization techniques for the study area.

The scope of these studies, because of the broad scale of subjects covered, could not individually be dealt with in great depth. Sufficient analyses were made to indicate the trend of reactions and responses, and to illustrate the techniques which can be used in water quality studies. The manpower requirements to conduct water quality studies in river basins were also of interest in this study, to permit additional insight into future requirements. In addition, the research techniques and methodology developed for the Skunk River basin at Ames may find more widespread application in other areas of Iowa and in the midwest.

Accomplishment of the stated objectives should enlarge considerably the field of basic and applied knowledge of water pollution and stream water quality aspects in Iowa.

IX. HYDROLOGIC CHARACTERISTICS OF IOWA STREAMS

A. General

The hydrologic variability of Iowa streams has an impact on the establishment and enforcement of realistic and reasonable water quality standards. For instance, the discharge of the Des Moines River at Ottumwa (drainage area of 13,374 sq mi) has varied from a low of 30 cfs to a peak of 135,000 cfs. Similarly, the Skunk River near Ames (drainage area of 315 sq mi) has experienced a zero low flow and a peak discharge of 8,630 cfs (Schwob, 1958). Water quality, as measured by the sediment load or clarity, will deteriorate during flood periods as high sediment loads are experienced (U.S. Geological Survey, 1968). In addition, waste treatment or water pollution control plants frequently are bypassed during flood periods and storm sewer discharges also contribute waste residues to the stream. Water treatment plants using the surface water resource face increased expenditures if treatment costs are directly related to the amount of turbidity.

In the water quality studies conducted and reported herein, however, the high discharges will not be considered as being directly influential. Recreation along streams is unsafe or impossible during such periods, and in the upper Skunk River basin there is no continuous surface withdrawal of water for municipal or industrial use. The low-flow characteristics will assume greater importance in this study, since less dilution water is available for waste assimilation and the public becomes more conscious and concerned over obvious pollution and point source effects. With or without a reduction of wastes by treatment methods, the concentration of many pollutants in the streams will depend on the volume of dilution water (McKee and Wolf, 1963). For the purposes of water pollution control, the sanitary engineer characteristically has been interested primarily in minimum stream flows and their temporal persistence.

Because of these factors, the general relationship of the low-flow characteristics of Iowa streams to the water pollution problem was evaluated. The stream parameters included in the investigation were the magnitude and frequency of low-flow discharges, recorded temperature variations across the state, and stream assimilative capacity factors. Estimates were made of the general capability of Iowa streams to assimilate effluent discharge from water pollution control plants. Detailed examination and analysis of the low-flow characteristics of the upper Skunk River basin were made and are included as a final study item of this section.

B. Hydrologic Study Methods

Two statistical methods are available for interpreting low-flow data and computing the probability of occurrence of low flows of a selected magnitude (Schwob, 1958; Linsley et al., 1949, 1958; McKee and Wolf, 1963, Chow, 1964): (1) flow duration analysis and (2) low-flow frequency analysis. A "duration curve" is obtained through flow duration analysis. This an accumulated frequency curve of a continuous time series of discharge data. Because the data array is generated in terms of decreasing flow magnitude, irregardless of when the discharges occurred, the duration curve is independent of chronologic sequences. The accumulative frequency curve indicates the percent of time during the period of record which a given discharge was equalled or exceeded. For instance, at the magnitude of the 90% duration value, the indicated discharge would be equalled or exceeded 90% of the time; however, it might not be exceeded, on the average, for 36 days per year. Also, during drought years, flows less than the 90% value might be experienced for a much greater number of days. Conversely, during wet years with above normal precipitation the 90% value might be exceeded the entire year (assuming that the period of record was many years in length).

The flow duration curve for a given period of record is also sensitive to the interval of time selected for use. Average daily, monthly, or annual discharges may be used, although class intervals of daily discharges are customarily selected. The duration curve is useful in studying the availability of selected magnitudes of discharge for beneficial use and in related economic studies of engineering facilities (see Frankel, 1965a, 1965b). For example, if turbidity from mineral sediments is related to both discharge and cost of water treatment, then the duration curve can be used to obtain the average annual cost of removing the sediment. Flow duration data for the upper Skunk River basin are listed in Table 13, as reported by Schwob (1958).

The primary inadequacy of the duration curve method is its failure to indicate the sequential persistence of low flows, which is of utmost concern in stream water quality studies. "Low-flow frequency" analysis is a method devised for obtaining the hydrologic variability of a

Table 13. Discharge for selected duration percentages for streams in the Skunk River basin[a]

Stream	Drainage area, sq mi	Average discharge, cfs	Discharge, cfs, exceeded indicated percent of time: 5	20	50	80	90	95
Skunk River near Ames	315	135	580	180	43	4.0	1.3	0.55
North Skunk River near Sigourney	730	347	1,700	515	125	21	8.2	4.5
Skunk River near Oskaloosa	1,635	778	2,850	1,080	330	71	36	21
Skunk River at Coppock	2,916	1,435	5,700	2,100	620	150	79	54
Skunk River at Augusta	4,303	2,233	9,500	3,090	890	210	100	64

[a]Source: Schwob (1958), using the base period 1934-1953 for stations with 5 or more years of record.

chronological sequence of low flows. Daily streamflow records are analyzed to determine the magnitude and frequency of minimum flows at a stream gaging station for various periods of consecutive days. Common periods selected are 1-, 7-, 30-, 60-, 120-, and 183-day periods (Schwob, 1958). The annual series is used for the frequency analysis, with the minimum volume of streamflow for the selected period of days being determined for each of the years of record. This minimum volume is expressed as an average discharge for the selected period, in cfs. Thus, the smallest average discharges for 1-, 7-, 30-, 60-, 120- and 183-day periods for each year are tabulated for frequency analysis, and placed in an array of ascending values with the smallest value in the array being assigned the order number 1. The U.S. Geological Survey, using methods developed by Gumbel, has used the Weibull frequency distribution for computing the plotting position of each item in the array (Schwob, 1958; Benson, 1962; Federal Interagency Comm. on Water Resources, 1966):

$$T_r = \frac{n + 1}{m} \qquad (92)$$

where

T_r = average recurrence interval, years

n = number of items in the array, and

m = order number in the array of the discharge for which the recurrence interval is being computed.

Schwob, in completing the study of low-flow characteristics for Iowa streams (1958), made a graphical analysis of the plotted data and established for each station a relation between low-flow magnitude and its probability of recurrence in terms of low-flow frequency. A method of relating short-term records to long-term records (using long-term records at a gaging station of similar hydrologic characteristics) was developed, permitting several short-term records to be included in the long-term study. The common base period used in the 1958 study was 1934-1953, with individual station data being included for duration analysis through 1956. The results of the low-flow frequency study for the three long-term stations in the Skunk River basin are listed in Table 14.

The final selection of a design low flow for stream protection purposes and stream water quality improvement is somewhat analogous to the selection of design discharges for flood protection works, with the focus now being on the low flows instead of the high flows. McKee and Wolf (1963) noted that it was considered impractical in most instances, or infeasible, to design a water pollution abatement program that would achieve protection of the absolute lowest low flow which might be expected. Therefore, a lesser goal is accepted. Kneese (1962) observed that the choice of design flows is a dominant factor in planning water quality improvement programs, especially to the alternative cost calculation of low-flow augmentation. Both of the elements listed previously, the consecutive day period over which daily low flows are averaged and the time interval between occurrence of the low flows, must be considered as variables. Both can affect the optimum combination of abatement measures and the related optimum scale of pollution control facilities (Kneese, 1962, p. 39). If selected arbitrarily, albeit reasonably, then the designated magnitude and frequency become constraints in economic analysis, as was noted in a previous part of this study.

Table 14. Magnitude and frequency of annual low flow for the three long-term stations in the Skunk River basin, for indicated periods of days and recurrence intervals[a]

Stream	Period of days	Record low flow, cfs	Discharge, cfs, for indicated recurrence interval in years					
			1.05	2.	5	10	15	20
Skunk River near Ames, 315 sq mi	1	0.0	32	1.0	0.14	0.06	0.04	0.03
	7	0.0	40	1.3	0.18	0.08	0.06	0.05
	30	0.0	55	2.0	0.23	0.11	0.08	0.07
	60	0.02	77	5.0	0.57	0.24	0.17	0.14
	120	0.07	126	11	1.1	0.44	0.32	0.27
	183	0.20	180	27	2.8	0.98	0.66	0.54
Skunk River at Coppock[b], 2,916 sq mi	1	8.0	277	50	16	9.0	6.7	5.5
	7	8.7	335	67	24	15	12	11
	30	11.2	440	96	38	23	19	18
	60	21.2	577	140	55	35	29	26
	120	45.8	875	204	93	61	50	44
	183	65.8	1,240	283	131	88	73	64
Skunk River at Augusta, 4,303 sq mi	1	7.0	516	60	15	7.7	5.6	4.7
	7	7.43	688	86	25	14	11	9.5
	30	17.3	818	142	43	24	18	16
	60	29.1	1,080	224	73	40	31	26
	120	42.0	1,640	374	138	82	64	52
	183	53.1	2,330	525	219	129	103	86

[a]Source: Schwob (1958), using the base period 1934-1953 for low-flow frequency analysis, but listing record low flows through the water year 1956.

[b]Station discontinued in 1944, low flows in 1950's not recorded.

According to Kneese, if pollution damages to downstream interests could be identified and measured in monetary terms, then selection of design flows could follow marginal economic theory. However, it was noted that the design flows for both treatment plants and flow augmentation in reservoir projects usually are selected arbitrarily, or actually specified by state law. The "favorite" that appeared most frequently was the 7-day, once in 10-yr low flow. This value has been adopted in Iowa as the lowest discharge for which stream water quality criteria and standards are to apply (Iowa Water Pollution Control Commission, 1967). However, Kneese concluded that cost minimization strategy should include both of these low-flow factors as variables (the period and the interval), and the design flow variations included in economic analysis.

Several more advanced methods of low-flow and storage frequency analysis can be used today (Matalas, 1963; Chow, 1964; Fiering, 1966, Yevdjevich, 1966). However, in simulating consecutive X years of record, based upon means and variances derived from the historic records, present methods have principally been limited to monthly low-flow data. The methods of Schwob were continued in this study so that comparative results would be obtained and also to permit the 1-, 3-, 7-, 14-, 30- and 60-day periods to be analyzed in conformance with the adopted 7-day period in the state water quality standards for Iowa streams.

C. The Hydrologic Variability of Iowa Streams

1. Low-flow variability in central Iowa

The data included in Tables 13 and 14 provide several indications of low-flow variability in the Skunk River basin. The average discharge, in relation to drainage area, increases modestly with drainage area size from 0.43 csm (cfs per square mile) near Ames to 0.52 csm at Augusta. In terms of total magnitude, the average discharge increases over 16-fold (135 to 2,233 cfs) with the distance involved being about 206 mi (U.S. Corps of Engineers, 1964). This represents an increase of 100 cfs every 10 mi of river at the average discharge level, a rough approximation in view of the point sources of tributary inflow. The data of Schwob (1958) show that at all stations the average discharge is exceeded less than 30% of the time; conversely, the streamflow is less than the average discharge over 70% of the time. Variability also decreases as the drainage area increases. The duration data included in Table 13 illustrate this clearly. The low flow at the 90% level is only 1% of the average discharge at Ames, but increases to 4.6% at Oskaloosa and 5.5% at Coppock. However, it reduces to 4.5% at Augusta, the most downstream station.

Examination of the low-flow frequency data in Table 14 provides similar information and results. The record low-flow and frequency data for the Skunk River near Ames provided the first indication in the current study that the amount of dilution water in Iowa is frequently very low or nonexistent. Low-flow discharge at Ames recedes to a value of 1.0 to 1.3 cfs every other year (1- to 7-day periods) and for the selected 7-day, 10-yr criteria adopted by the State of Iowa the discharge is only 0.08 cfs (315 sq mi drainage area). This flow is very small for the dilution of effluent discharge at Ames, which had a population of 34,835 in 1965. The treated waste discharge averaged 5.2 cfs (1965) at the outfall where the drainage area is 556 sq mi and the 7-day, 10-yr low flow is estimated to be 0.16 cfs.

The low-flow magnitude in the Skunk River basin for a given duration or frequency value increases rapidly in the downstream direction. At the two downstream stations for which data are available, Coppock and Augusta, the increases are shown in Table 14. The 7-day, 10-yr low flow increases from 0.08 cfs at Ames to 14 cfs at Augusta, an increase of almost 20-fold. The slight reduction in magnitude of low-flow discharge between the Coppock and Augusta stations, at the higher recurrence intervals, may be due more to the difference in actual period of record studied than in physiographic or other hydrologic differences, since the Coppock station was discontinued in 1944 prior to the 1950's when a severe drought period was experienced.

There is an obvious lack of adequate streamflow (for water quality control or other beneficial uses) in the upper Skunk River basin for almost any selection of frequency and period of days, especially for recurrence intervals greater than the every-other-year occurrence (2-yr frequency). However, the equivalency between consecutive days in a selected period and recurrence intervals (for constant discharge) as discussed by Kneese (1962) is apparent in the data shown in Table 14. For example, at Augusta, a discharge in the range of 60 to 70 cfs corresponds with combinations of (1) 1-day, 2-yr, (2) 60-day, 5-yr,

(3) 90-day, 10-yr, (4) 120-day, 15-yr, and (5) 150-day, 20-yr (as interpolated). Because of the tremendous variation in low-flow characteristics with drainage area size in the Skunk River basin and of the general concern regarding adequacy of low flows for assimilative purposes, further study appeared desirable. Additional investigation of the hydrologic variability was made to determine the regional characteristics of Iowa low flows as they might influence the waste assimilative capacity and stream water quality.

2. Average annual hydrologic relationships in Iowa

The low-flow characteristics, flood characteristics, and average hydrologic conditions for Iowa streams have been reported in several publications (Iowa Natural Resources Council, 1959; Schwob, 1953, 1958, 1964, 1966). In the 1958 bulletin, Schwob stated that variations in low-flow characteristics could be attributed to differences in topography, geology, soils and normal rainfall. The variations in normal annual precipitation (1931-1960 period) and average annual discharge of Iowa streams can be used to illustrate the general hydrologic variations experienced in the state.

The isohyetal map of normal annual precipitation in Iowa for the U.S. Weather Bureau 30-yr normal period, 1931-1960, is shown in Fig. 10 (Shaw and Waite, 1964; Schwob, 1966). The average annual runoff for Iowa streams (U.S. Geological Survey, 1965) is shown in Fig. 11. Precipitation varies across the state, from 25 in. in the far northwest corner of Iowa to 34 to 35 in. in the southeast and east central portions. The eastern two-thirds of the state receives on the average

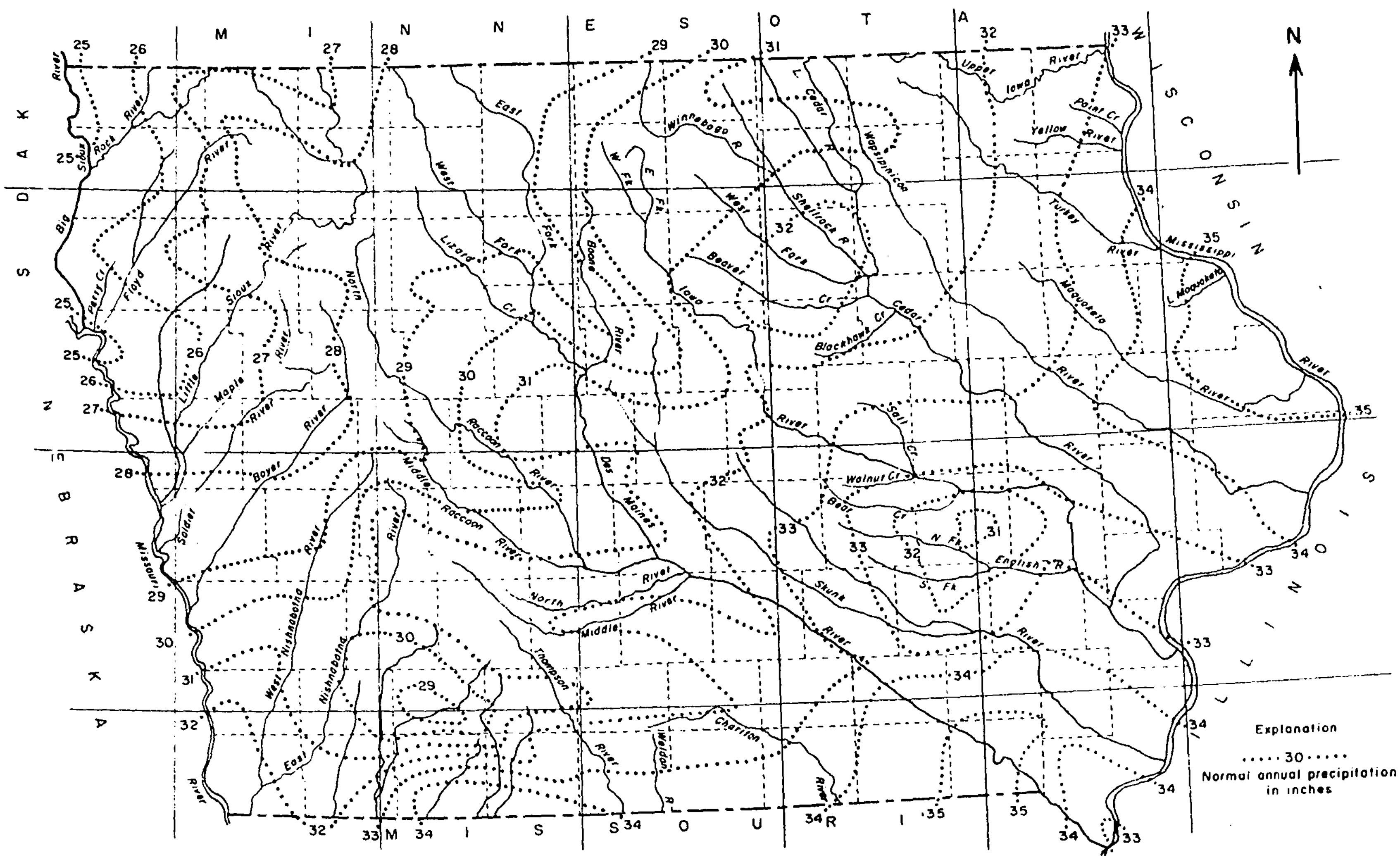

Fig. 10. Isohyetal map of Iowa normal annual precipitation in inches (after Schwob, 1966).

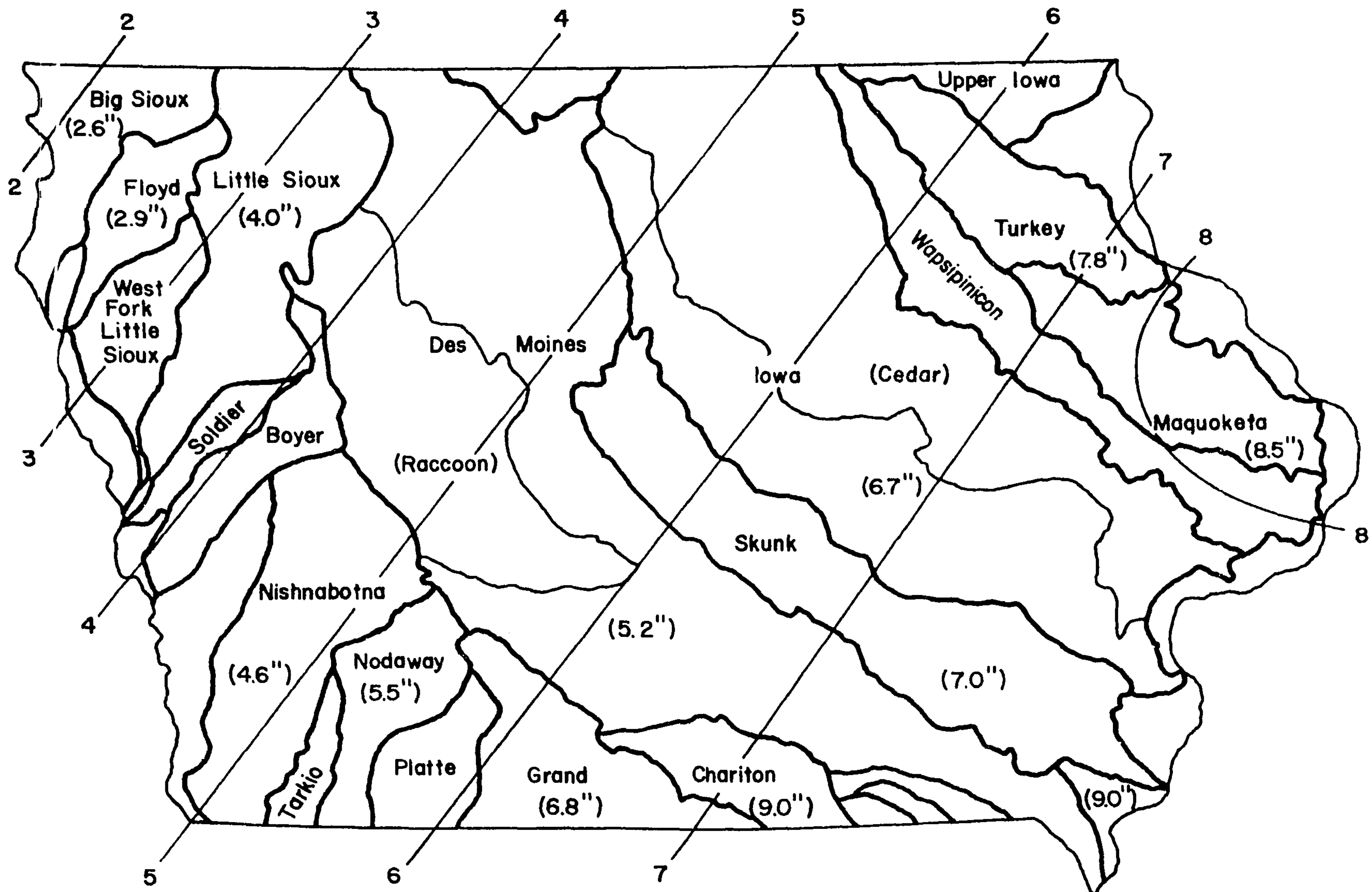

Fig. 11. Average annual runoff of Iowa streams as shown by isopleths and basin averages, in inches (after U.S. Geological Survey, 1965).

more than 30 in., annually. The annual average streamflow, in terms of inches of runoff, increases in magnitude from northwest to southeast and east in a similar manner, from 2 in. to 8^+ in., as shown by the isopleths of runoff in Fig. 11. Representative runoff values for selected basins are also shown. Because the variations in annual runoff coincide closely with the spatial variations in precipitation, it can be concluded that precipitation is the primary determinant of streamflow on an average annual runoff basis. However, the influence of evapotranspiration should also be included, to assist in explaining the difference between annual precipitation and runoff. A simple hydrologic equation can be applied to the data shown in Figs. 10 and 11:

$$P = Q + ET \tag{93}$$

where

P = normal annual precipitation, long-term basis,

Q = average annual runoff on a similar long-term basis, and

ET = average annual evapotranspiration experienced on a long-term basis, each expressed in inches.

Using the long-term basis smooths the annual changes in groundwater storage and these effects can be neglected in the hydrologic equation. The following isohyets of normal annual precipitation and isopleths of runoff coincide to a general extent: 34 and 8, 33 and 7, 32 and 6, 31 and 5, 29 and 4, 28 and 3, and 25-26 and 2. Subtraction of these two related values indicates that long-term evapotranspiration (ET) in the eastern two-thirds of Iowa is a fairly uniform value of 26 in. per year. It reduces to a value of 23 to 25 in. in the west and northwest parts of the state. Variations in mean annual temperature across the state will influence the evapotranspiration cycle, since the mean annual temperature varies from 50 to 52 deg F in southern Iowa to 46 to 48 deg F in the north (U.S. Weather Bureau, 1959; Shaw and Waite, 1964). But, in general, if the long-term annual precipitation is less than 28 or 29 in., little runoff is observed (2 to 3 in. at most).

It can be concluded that the average streamflow which is available for beneficial use, including water quality control, is the residual amount remaining after evapotranspiration exacts its requirement. The northwest part of the state is particularly deficient in average streamflow, and may be even more deficient in low flows if a substantial portion of the annual runoff is derived from direct surface runoff during storms. If the evapotranspiration potential in the northwest part of the state equals the experienced value of 26 in. in the remainder of the state, then little, if any, dry weather flow may occur.

A similar analysis may be made for the Skunk River basin. The Skunk River basin above Ames (315 sq mi) receives an annual average precipitation of 30.5 in. (Schwob, 1966) and for the entire basin above Augusta, 32.8 in. (Schwob, 1966; Iowa Natural Resources Council, 1957). The average annual runoff, based on the data of Table 13, is 5.8 in. (csm x 13.6) at Ames and 7.0 in. at Augusta. This gives ET values of 25 to 26 in., in conformance with the values previously determined. Therefore, an average amount of runoff can be expected on a long-term basis. However, low-flow characteristics remain to be investigated, and additional variables including topography, geology, and other physiographic features may influence the low-flow relationships. The upper

Skunk River basin already appears to be somewhat unique, in that the average discharge (or average annual runoff) is almost 6 in., normal for the region, but the low-flow characteristics as shown in Table 14 are very poor. The question remains as to how extensive this deficiency in low flows will be for other river basins of similar or smaller size within the state.

3. Regional trends in low-flow characteristics

Data presented by Schwob (1958) illustrate the variations experienced in the low-flow characteristics of Iowa streams. Flow duration curves were developed in the 1958 study for 84 stations although only 20 of the records extended entirely through the base period (1934-1953 water years). For the low-flow frequency portion of the 1958 study, Schwob selected 51 gaging stations having 10 or more years of record. For the base period, the low-flow duration and frequency data were converted to csm values and placed in a summary table (Schwob, 1958, pp. 13-22), beginning with stations in the northwest part of the state and continuing to the west and southwest. These summaries provide a convenient means of analyzing broad regional characteristics of low flows for Iowa streams. Four categories were selected for additional study; the 90% duration; 7-day, 10-yr frequency; 7-day, 20-yr frequency; and 30-day, 10-yr frequency.

Initial inspection of the 90% duration data indicated that streams with less than 100 sq mi drainage area frequently go dry, with values of zero flow above the 90% magnitude. There also was some evidence of a substantial increase in low-flow discharge as drainage areas reached

1,000 sq mi or more. As a result, three size categories were selected:

1. Large streams, with drainage areas greater than 1,000 sq mi.
2. Intermediate size streams, 100 to 1,000 sq mi.
3. Small streams, less than 100 sq mi.

Additional inspection and initial plots of Schwob's data also indicated a general regional trend of decreasing low flow for each of the four categories of duration or frequency, beginning with the northeast streams and progressing to the southwest and west. Three regional groups of stream basins were identified and designated. These are shown in Fig. 12. Schwob's data for the two larger size categories, 100 to 1,000 sq mi and greater than 1,000 sq mi, were included in the final analysis. The unit area discharge, csm, was plotted versus drainage area for the four duration and frequency categories, as indicated in Figs. 13, 14, 15 and 16 for the 90% duration; 7-day, 10-yr and 20-yr frequency values; and the 30-day, 10-yr frequency, respectively.

The data shown in Figs. 13-16 illustrate the tremendous difference in magnitude of low flow which can be expected in Iowa. The variations become even more extreme for drainage areas less than 100 sq mi, and it is impossible to include the data on a single plot of reasonable size. The envelope curves were drawn to show the regional trend of low-flow characteristics for streams greater than 100 sq mi in size.

The data as plotted in Figs. 13-16, and inspection of Schwob's summary data, indicate a definite trend of increasing unit discharge in each river basin and region as the drainage area increases. This is to be expected, if the low flows of the magnitude studied fall within

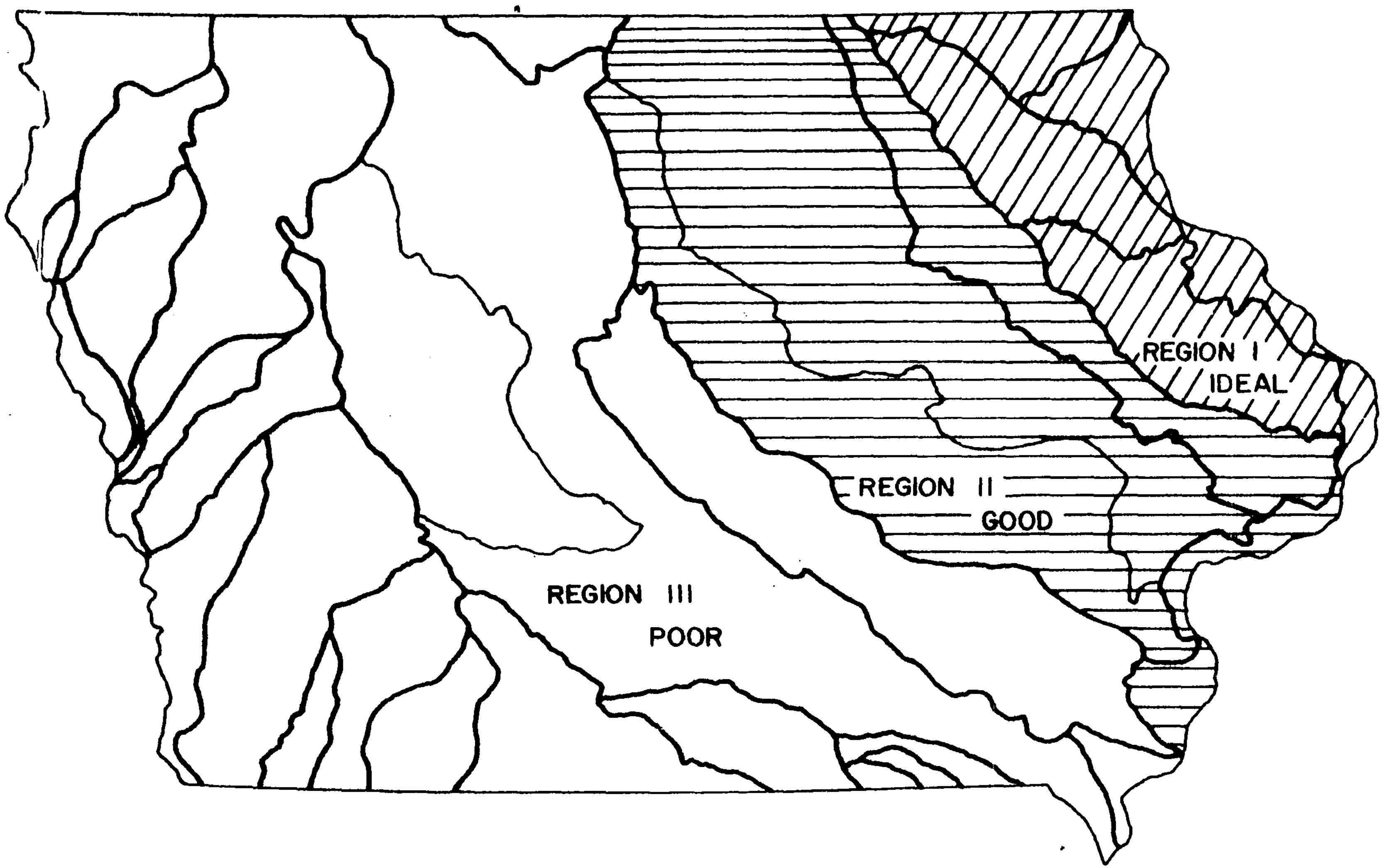

Fig. 12. Identification of three low-flow regions in Iowa based on low-flow characteristics. (See Fig. 11 for basin designations.)

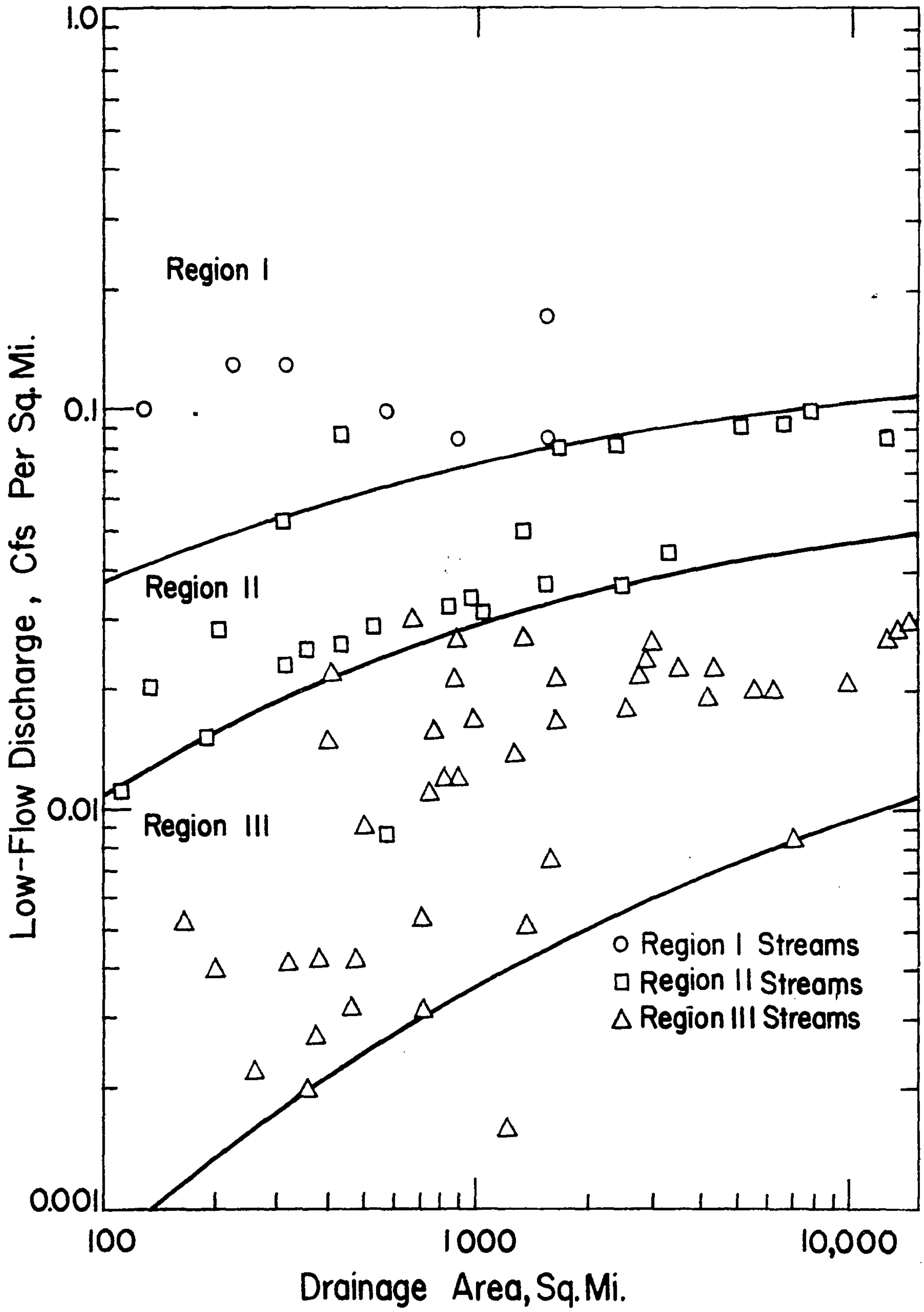

Fig. 13. Low-flow discharge of Iowa streams at U.S.G.S. gaging stations, for the 90% duration value.

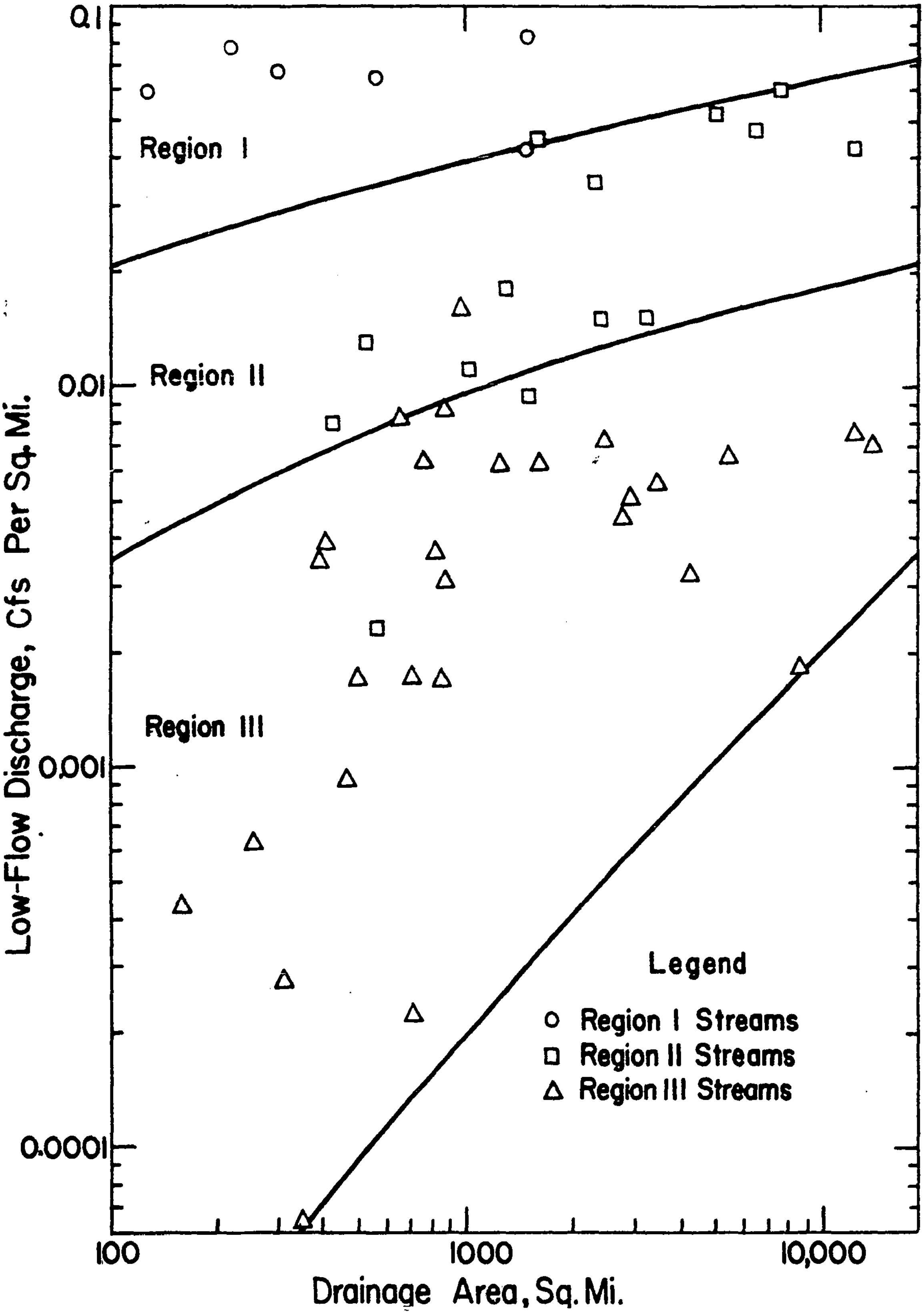

Fig. 14. Low-flow discharge of Iowa streams at U.S.G.S. gaging stations, for the 7-day, 10-yr recurrence interval.

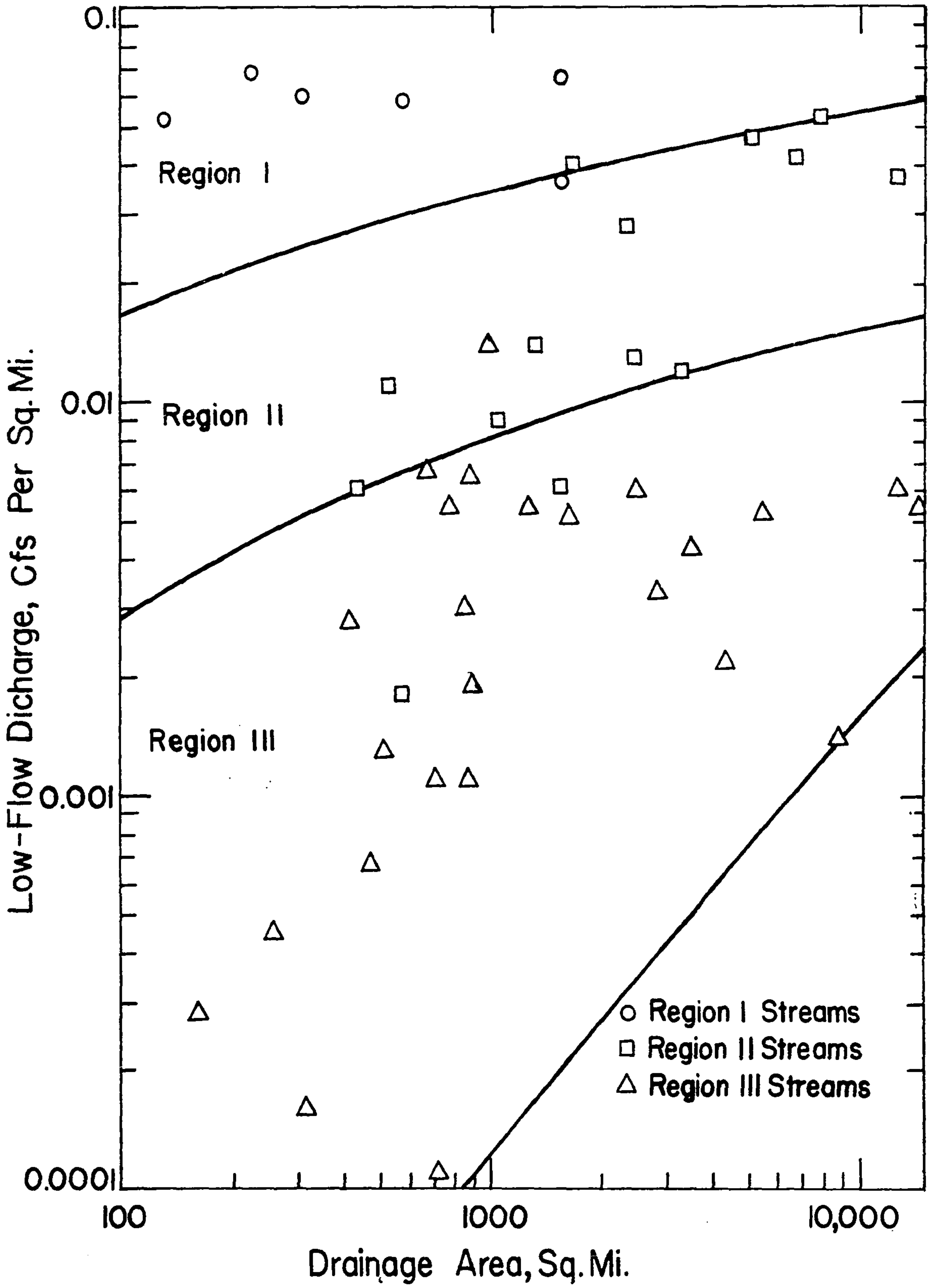

Fig. 15. Low-flow discharge of Iowa streams at U.S.G.S. gaging stations, for the 7-day, 20-yr recurrence interval.

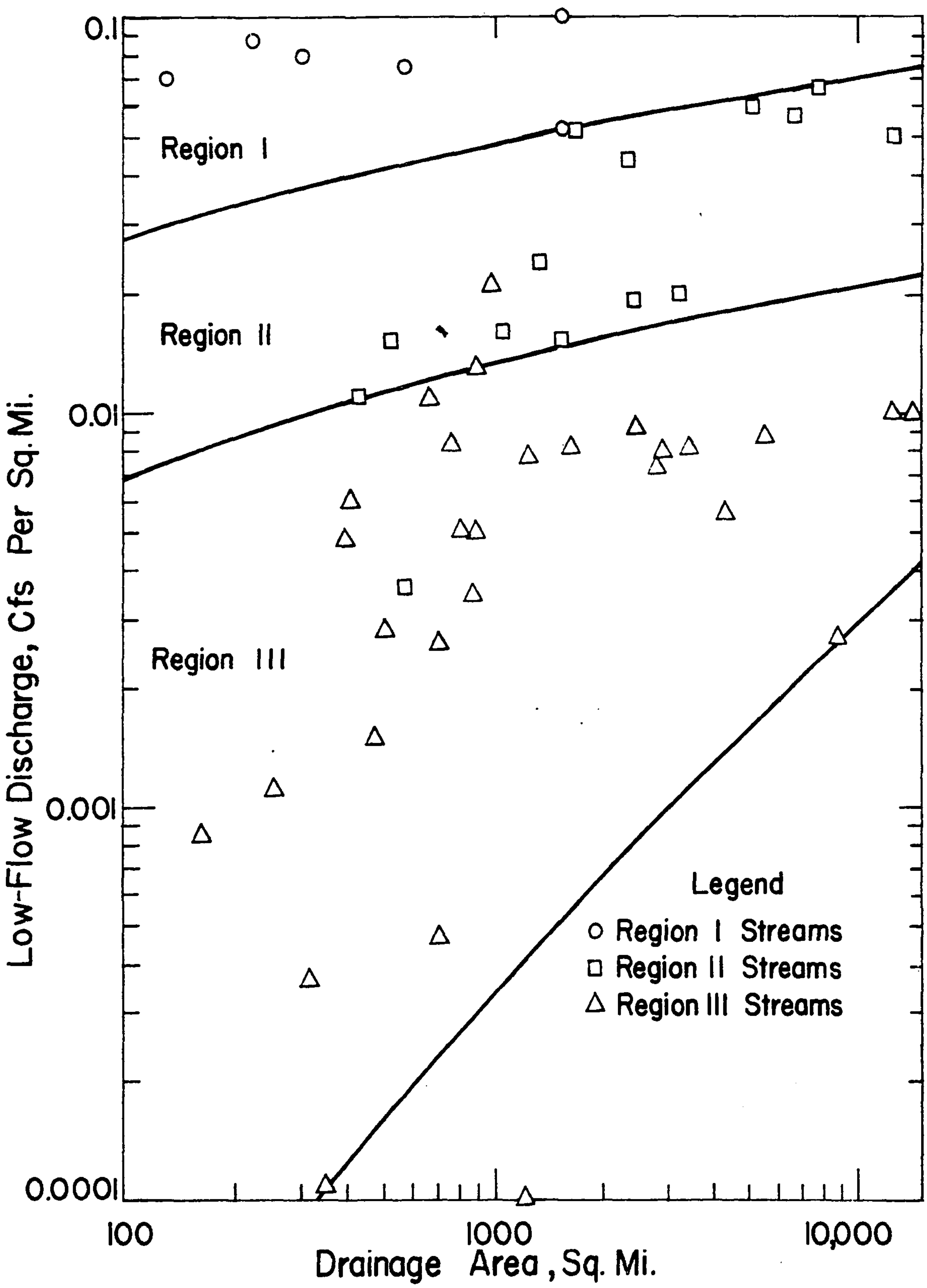

Fig. 16. Low-flow discharge of Iowa streams at U.S.G.S. gaging stations, for the 30-day, 10-yr recurrence interval.

the concept of the base flow of the stream. The valleys and streams become more incised vertically as the drainage area increases, accompanied also by a broadening of the valleys in the lateral extent. Additional groundwater contribution from intercepted bedrock formations and upland glacial deposits may be experienced, and in addition alluvial material in the wider valleys can contribute larger quantities of seepage discharge. Very small drainage areas, less than 10 to 20 sq mi, have very poor low-flow characteristics if they are located in upland prairie areas of the state. The Ralston Creek (and Rapid Creek) watersheds near Iowa City are indicative of this trait (Howe and Warnock, 1960).

The results of this analysis illustrate quantitatively what has generally been accepted in a qualitative sense, namely that the streams which have the greatest sustained low flows are those streams located in the far northeast part of the state. As reported by Trowbridge (1966), this is the region of the state with the least evidence of glaciation, of considerable karst topography and with drift remnants and residual mantle overlying the adjacent bedrock layer. The deeply incised valleys, in combination with the other geological features, provide a ready gradient for groundwater contribution to streamflow.

4. Identification of three low-flow regions

The boundary or envelope curves shown in Figs. 13-16 show that the streams in Iowa can be placed in three categories, Regions I, II, and III, although there is little differentiation at the boundaries. Inspection of the 90% duration data in Fig. 13 reveals, first, that one station in Region II plots in the data of Region I. This is the

Cedar River at Austin (425 sq mi), with a short-term record not included in the low-flow frequency analysis. The station description mentions that the gaging station is located 1 mi downstream of the city. Therefore, it may be suspected that effluent discharge may be influencing the low-flow record obtained at the site. A second anomoly is noted in the one additional station in Region II that plots low in the data of Region III. This is the English River at Kalona (573 sq mi), which lies next to the Skunk River basin (Region III) in southeast Iowa. With a 17-yr record (1939-1956) used in the study, the differences cannot be explained by lack of a long-term record. Bear Creek at Ladora (189 sq mi) also has relatively lower discharge during dry weather periods, plots on the boundary curve in Fig. 13, and its short-term record was not included in the frequency analysis. Both streams are outside the Iowan lobe of the Wisconsin glacial stage and are located on the Kansan, as are the lower Skunk River basin and other southern Iowa stream basins (Iowa Natural Resources Council, 1957). This factor appears to be the major physiographic influence; however, if no bedrock formations are encountered along the length of the basin, a lack of groundwater interception could be an additional factor causing the less favorable low-flow characteristics in this area.

A third basin which plots out of its regional position is the South Raccoon River at Redfield (988 sq mi). It has a much better base flow than other streams in the region. Known outcrops of bedrock and/or the influence of several water pollution control plants located along the stream are two plausible explanations for the variation noted. The fourth stream basin for which an explanation should be made is the West

Fork Des Moines River at Jackson, Minnesota (1,220 sq mi) which has much more deficient low flow than the same stream at downstream points. Much of the basin above Jackson is in an area of lakes and sloughs which have controlled outlets. As a result, little if any outflow is experienced during dry weather periods. In reality, the drainage areas for all of the main stem gaging stations on the Des Moines River should be adjusted downward, which in effect would move all of its points to the left in Figs. 13-16. With these exceptions, the remainder of the data show that the streams in Iowa can be placed in the general regional categories proposed, Regions I, II, and III, as shown in Fig. 12.

Additional identification of these regions can now be summarized:

1. Region I, Ideal

    a. Ideal low-flow characteristics.

    b. Includes: Northeast Iowa stream basins, involving the Upper Iowa River, Paint Creek, Yellow River, Turkey River, Little Maquoketa River, Maquoketa River, and local tributaries of the Mississippi River in this area.

    c. General magnitude of low flows: Streams of almost all sizes have well sustained base flows, with the possible exception of very small drainage areas (less than 10 sq mi) located in upland areas of a major basin.

2. Region II, Good

    a. Good low-flow characteristics.

    b. Includes: Eastern Iowa basins such as the Wapsipinicon River, Cedar River, Iowa River, and local tributaries of the Mississippi River in the reach between the Iowa and Wapsipinicon Rivers; perhaps all local tributaries of the Mississippi River between the Iowa and Des Moines Rivers should be included also.

    c. General magnitude of low flows: Large streams have good low-flow characteristics, approaching those in

Region I in some cases. However, intermediate size and small stream basins have only fair to poor low-flow characteristics, with a wide range of unit discharge values being experienced between small and large basins.

3. Region III, Poor

   a. Poor low-flow characteristics.

   b. Includes: Remainder of the state, the Skunk River, Des Moines River, and all southern and western Iowa streams (see Fig. 11), some of which drain to the Mississippi River, and the remainder drain either to the Missouri River directly, or to the Big Sioux River.

   c. General magnitude of low flows: Major streams, above 1,000 sq mi, have only fair low flows, intermediate streams have poor low-flow characteristics, and the small streams have such very poor low base flows that they may be intermittent with long periods of zero flow.

These general descriptions of the variations among the three regions are listed in quantitative terms in Table 15. This provides a range of values with which additional relationships to water quality and dilution requirements can be considered.

Table 15. Classification of Iowa streams by low-flow characteristics[a]

Region	Size of stream	Range of magnitude of low-flow discharge, csm: 90% duration value	Range of magnitude of low-flow discharge, csm: 7-day, 10-yr low flow
I. Ideal	Large	0.085 - 0.170	0.04 - 0.10
	Intermediate	0.04 - 0.10	0.02 - 0.08
	Small	0.02 - 0.08	0.01 - 0.06
II. Good	Large	0.03 - 0.10	0.01 - 0.06
	Intermediate	0.01 - 0.07	0.008 - 0.02
	Small	0 - 0.03	0 - 0.006
III. Poor	Large	0.004 - 0.03	0.002 - 0.01
	Intermediate	0.001 - 0.025	0.0001 - 0.008
	Small	0 - 0.001	0 - 0.003

[a]Analysis made using data from Schwob (1958); see also Figs. 12-16.

5. Significance of the experienced variations in low flows

The variations which exist in the low-flow characteristics of Iowa streams may have a substantial impact on water pollution control measures and efforts to initiate a realistic stream improvement program. Two examples will be used to illustrate the magnitude of this variation in terms of low flows available for dilution of effluents discharged from water pollution control plants. The first comparison will be made for two large streams, one in Region II and one in Region III. These streams, with gaging stations at each location, are the Cedar River at Waterloo (5,146 sq mi) and the Des Moines River at Boone (5,511 sq mi). Both unit discharge values and total discharges are listed in Table 16 for the 90% duration and the 7-day, 10-yr frequency events. McKee and Wolf (1963) used the former as a measure of low-

Table 16. Two comparisons which illustrate the magnitude of the variations experienced in low-flow characteristics in Iowa[a]

Example	Region	Stream and location	D.A., sq mi	Low-flow discharge for indicated condition: 90% duration, csm	90% duration, cfs	7-day, 10-yr low flow, csm	7-day, 10-yr low flow, cfs
1	II	Cedar River at Waterloo	5,146	0.092	473	0.052	267
	III	Des Moines River at Boone	5,511	0.020	110	0.0065	36
2	I	Upper Iowa River at Decorah	568	0.10	56.8	0.064	36.3
	III	Skunk River at Ames (below Squaw Creek)	556	0.0041	2.3	0.00029	0.16

[a]Analysis of data obtained from Schwob (1958).

flow probability and the Iowa Water Pollution Control Commission (1967) has adopted the latter.

The second comparison will be made to illustrate the impact of these low-flow variations at respective communities having waste treatment facilities. The two locations are the Upper Iowa River at Decorah (568 sq mi; 7,054 population in 1965) in Region I and the Skunk River at Ames (below Squaw Creek, 556 sq mi; 34,826 population in 1965). Because the gaging station below Squaw Creek was installed only in 1952 and was not included in Schwob's study, the data for the Skunk River near Ames (315 sq mi) was adjusted both for the direct increase in drainage area and for the observed increase in unit discharge as the drainage area increases. The comparative statistics for these two locations are included also in Table 16.

The results of the first comparison, between the Cedar and Des Moines Rivers, illustrate clearly the deficient nature of low-flow discharge in the streams in Region III. There is a seven-fold difference in low-flow values for the 7-day, 10-yr event, and over four-fold for the 90% values. Comparison between examples 1 and 2 shows that the Upper Iowa River at Decorah has the same 7-day, 10-yr low flow as does the Des Moines River at Boone, but has only one-tenth of the drainage area of the latter. These variations become even more noticeable in the second comparison between the Upper Iowa and Skunk Rivers. The difference is a factor of 25 times for the 90% duration value, and for the selected Iowa criteria of the 7-day, 10-yr event the Skunk River has only one-half of 1% of the low flow of the Upper Iowa River.

Establishment of the 7-day, 10-yr low-flow frequency uniformly across the state represents a decided advantage for waste dischargers in Regions I and II. As noted previously, the city of Ames discharged an average of 5.2 cfs from its water pollution control plant in 1965. If it is assumed that the city of Decorah has the same per capita contribution of waste water, then the northeast Iowa community discharges about 1 cfs to a stream which has a 7-day, 10-yr low-flow discharge of 36 cfs, or a dilution ratio of 36 to 1. The city of Ames must discharge over 5 cfs to an essentially dry stream, 0.16 cfs. The physical desirability of obtaining low-flow augmentation from the proposed Ames Reservoir assumes considerable importance, in view of the deficiency of streamflow at the criteria level established by the Iowa Water Pollution Control Commission. The Commission, in view of this deficiency, has not yet classified the Skunk River upstream of Colfax as a recreation or aquatic habitat area. Alternatives to the need for low-flow augmentation include tertiary treatment and/or temporary storage of effluent discharges.

D. Statewide Estimates of the General Assimilative Capacity of Iowa Streams

1. Basic concepts

The overall magnitude of the problem of meeting and maintaining stream water quality standards established for Iowa was studied on a regional basis by comparing effluent dilution requirements (as published for average conditions) with the natural low-flow characteristics of the streams. The dilution requirements determined in this study were based on the dissolved oxygen required for assimilation of the carbonaceous BOD_u loading (ultimate biochemical oxygen demand) discharged to the stream as effluent from a point source, with no additional waste or tributary inflow prior to recovery of the assimilative capacity at downstream points. Sufficient residual oxygen to support an aquatic habitat and maintain aerobic conditions in the stream can be assured by using the 4 mg/l minimum DO of the Iowa standards as applied to all major streams (assuming only the small tributaries in northeast Iowa are classified as cold water habitats). Published relationships for dilution factors and for the self-purification coefficient, f, used in regional studies of pollution abatement water requirements, and including work by Reid (U.S. Senate, 1960i), are summarized in Table 17.

Table 17. General relationships for regional dilution requirements and the self purification factor[a]

Type of stream	Dilution requirements, cfs per 1,000 PE			Self-purification factor, f
	Raw sewage	80% treatment	85% treatment	
Sluggish streams	10	2.0	1.5	1.0 - 1.5
Average value	6	1.2	0.9	2.0 - 3.0
Swift streams	2 - 3	0.4 - 0.6	0.3 - 0.45	3.0 - 5.0

[a]Source: Summarized in Fair and Geyer (1954) and U.S. Senate (1960i).

2. Effect of regional temperature variations on permissible waste loads in Iowa streams

In this initial appraisal, the boundary conditions expressed in Eqs. 52-56 were used, these being the ratios of permissible organic loading to the critical oxygen deficit ($D_c = C_s - 4.0$). The least stress on the stream is achieved using Eqs. 53 and 54, with $D_a = 0$ and assuming the stream $BOD_u = 0$. However, this is unrealistic since it requires both effluent and stream water to be at the saturation DO value, a somewhat unlikely event. Introducing Eqs. 55 and 56 may be too severe, since it assumes $D_a = D_c$. Using methods outlined by Fair and Geyer (1954), an intermediate value of $D_a = \frac{1}{2} D_c$ was introduced to represent an effluent and stream discharge that was below the DO saturation value. The stream BOD_u was considered negligible in this study to simplify the analysis. Dilution requirements per 1,000 PE were made for summer conditions only, although it is recognized that winter conditions may become much more critical if heavy ice cover reduces the reaeration coefficient to zero.

Regional differences in temperatures of Iowa streams also favor the northeast stream basins insofar as available DO values are concerned, since stream temperatures are lower. An initial appraisal of temperatures, using U.S.G.S. data, indicated that summer season differences could approach the following: Region I, 22 deg C (72 deg F); Region II, 27 deg C (81 deg F); and Region III, 32 deg C (90 deg F). However, additional survey of temperature records indicated that the peak summer month temperatures for larger streams in northeast Iowa were higher than those originally selected. Data summarized by the Iowa Water Pollution

Control Commission (1968) were used in the final computations, and the following temperature variations were adopted for use as average summer month temperatures: Region I, 27 deg C (81 deg F); Region II, 30 deg C (86 deg F); and Region III, 32 deg C (90 deg F). These values are considered adequate to demonstrate the relative differences among the three regions in their respective ability to assimilate effluent discharge from water pollution control plants.

It is further assumed that the nonconsumptive portion of water use arriving at a water pollution control plant is 100 gpcd, the daily per capita BOD loading is 0.25 pcd of BOD_u, equivalent to a raw sewage BOD_u of 300 mg/l. To provide a range of values for the self purification coefficient, f, that might be characteristic of Iowa streams, values of 2.0 and 4.0 are adopted to represent a reasonable range. Large streams probably are represented best by the lower value of f, and the intermediate size streams by the larger value.

Introduction of an intermediate value of $D_a = \frac{1}{2} D_c$ requires additional mathematical treatment of the critical deficit equations, Eqs. 47 and 48. Fair and Geyer (1954) presented graphical relationships for intermediate values of D_a. The applicable equations were redeveloped in this study to permit numerical analysis. Equations 47 and 48 can be combined to yield

$$\frac{L_a}{D_c} = (f)^{\frac{f}{f-1}} [1 - (f - 1) \frac{D_a}{L_a}]^{\frac{1}{f-1}} \tag{94}$$

Introducing the relationship $D_a = bD_c$, for $0 \leq b \leq 1$, to represent intermediate values of D_a between the boundary values of 0 and 1 permits the following equality to be established between the permissible loading to the stream and the self-purification coefficient, f:

$$\left(\frac{L_a}{D_c}\right)^f = \frac{L_a}{D_c}(f)^f - (f - 1)\, b\, (f)^f \tag{95}$$

Neither Eq. 94 or 95 can be solved directly for the L_a/D_c ratio; however, in the form expressed in Eq. 95, a trial and error solution can be obtained fairly rapidly, or an iterative procedure can be used in digital computer programming to provide accurate results.

Computations for determining the permissible organic loading for streams in the three regions are summarized in Table 18. Saturation DO values were reduced to conform to the average elevation of Iowa streams. Maximum allowable values for L_a (combined river and effluent discharge downstream of the point of discharge) are shown in Lines 12 and 14, for f values of 2.0 and 4.0 respectively. These results indicate that the Region III streams have about 25 to 30% less assimilative capacity than Region I streams due to the temperature variations. Residual BOD_u's for 80, 85, 90, and 95% treatment efficiencies are listed in Lines 16-19, for the assumed input value of 300 mg/l. A similar analysis could be made using pounds of BOD_u per capita per day rather than using the mg/l concept, but the same organic loading would be obtained.

3. <u>Determining stream dilution requirements</u>

The dilution requirements (Q_r of Eq. 1) for the treatment efficiencies listed in Table 18 are obtained by equating the oxygen demanding substances in the effluent discharge to the permissible loadings given in Table 18. The residual BOD_u values of the effluent become $(L_a)_e$ values,

Table 18. Permissible organic loadings for streams in Regions I, II, and III

Line	Item	Value at indicated temperature Standard conditions	Region I	Region II	Region III
1.	Temperature, deg C	20	27	30	32
2.	Temperature, deg F	68	81	86	90
3.	BOD_u loading, pcd	0.25	0.25	0.25	0.25
4.	BOD_u loading, mg/l at 100 gpcd	300	300	300	300
5.	f, low estimate	2.0	1.75	1.60	1.53
6.	f, high estimate	4.0	3.50	3.21	3.07
7.	C_s, sea level, mg/l	9.02	7.87	7.44	7.17
8.	C_s, 900 to 1,000 ft elev., mg/l	8.7	7.6	7.2	6.9
9.	Minimum DO, for aquatic habitat, mg/l	4.0	4.0	4.0	4.0
10.	Maximum available DO, D_c, Line 8 to Line 9, mg/l	4.7	3.6	3.2	2.9
11.	L_a/D_c for f = 2.0 to 1.53[a]	3.41	3.10	2.91	2.82
12.	Maximum permissible L_a, mg/l, Line 10 x Line 11	16.0	11.2	9.3	8.2
13.	L_a/D_c for f = 4.0 to 3.07[a]	5.74	5.20	4.85	4.65
14.	Maximum permissible L_a, mg/l, Line 10 x Line 13	26.9	18.7	15.5	13.5
Residual BOD_u or $(L_a)_e$, mg/l					
15.	80% treatment	60	60	60	60
16.	85% treatment	45	45	45	45

[a]Computed using Eq. 95.

Table 18 (Continued)

Line	Item	Value at indicated temperature Standard conditions	Region I	Region II	Region III
17.	90% treatment	30	30	30	30
18.	95% treatment	15	15	15	15

the stream $(L_a)_r$ upstream of the point of effluent discharge is assumed to be negligible in comparison to the effluent value, and the maximum permissible loadings are the $(L_a)_m$ values to use in Eq. 1. The mathematical model for stream dilution water then becomes

$$(Q_e + Q_r)(L_a)_m = Q_e(L_a)_e \tag{96a}$$

or, solving for Q_r

$$Q_r = [\frac{(L_a)_e}{(L_a)_m} - 1]Q_e \tag{96b}$$

The estimated dilution requirements in the three regions, in terms of cfs per 1,000 PE, are listed in Table 19 for the 4 selected treatment efficiencies. The temperature variations, although not great, are sufficient to require about 50% more dilution water in Region III than in Region I. The sensitivity of the dilution requirement to treatment efficiency is quite evident in the results listed in Table 19. The dilution requirement diminishes rapidly with increased treatment efficiency, and for the assumed conditions there is little need for dilution water as efficiencies reach the 90 to 95% level. Under conditions of 95% efficiency and an f value of 4.0, the streams have the

Table 19. Preliminary estimates of dilution requirements in Regions I, II, and III[a]

		Estimated dilution requirements, cfs per 1,000 PE			
Waste treatment level, percent	f value	Standard (20 deg C)	Region I (27 deg C)	Region II (30 deg C)	Region III (32 deg C)
80	4.0	0.19	0.34	0.45	0.54
	2.0	0.43	0.68	0.85	0.98
85	4.0	0.10	0.22	0.30	0.36
	2.0	0.28	0.47	0.60	0.70
90	4.0	0.02	0.09	0.14	0.19
	2.0	0.14	0.26	0.35	0.41
95	4.0	–	–	–	0.02
	2.0	–	0.05	0.09	0.13

[a]Values computed from data in Lines 12, 14, and 15-18 of Table 18.

capability of assimilating the effluent organic loading even if there is little or no natural streamflow. Using Eq. 96b for the ratio Q_r/Q_e and the temperature and effluent conditions, usually experienced in the summer in Region III (Table 18, Lines 12, 14, 16 and 18), dilution ratios vary from 3.4 to 6.3 at the 80% treatment level to a range of 1.2 to about 2.6 at the 90% level. The data also provide an initial indication that for organic carbonaceous wastes, tertiary or advanced treatment (achieving 95% treatment or greater) might permit minimum stream DO requirements to be achieved even if dilution water is not available. At the 95% treatment level, computed values of Q_r/Q_e (Eq. 96b) are all less than one, and approach zero for Region I at f = 4.0. However, to achieve this condition under the assumed treatment levels, the effluent must contain a predetermined amount of DO ($D_a = \frac{1}{2} D_c$).

If the results shown in Table 19 are combined with the 7-day, 10-yr low-flow data at Decorah and at Ames, as discussed previously, then the population levels which could be supported by these streams can be compared. Using secondary treatment at an efficiency of 85%, the 36.3 cfs low flow at Decorah would support a PE of 50,000 to 100,000. Similarly, the 0.16 cfs low flow at Ames would support a PE of only 230 to 450, for the assumed conditions. If the assumed conditions are even approximately representative of actual stream conditions, then it is evident that primary treatment would be sufficient at Decorah on the Upper Iowa River but that tertiary treatment or low-flow augmentation is a necessity at Ames if desirable stream DO conditions are to be maintained. Because the northeast part of the state is emphasizing and assuming a recreation role in business and tourism, the higher treatment levels (then perhaps needed for minimum conditions) may be justified. These preliminary figures of Table 19 show also that at Ames, with a 1965 population of almost 35,000, low-flow augmentation of 12 to 25 cfs would be needed to maintain the 4 mg/l minimum DO for an aquatic habitat, for the 85% treatment level (35 x 0.36 and 35 x 0.70). Actual river studies of the Skunk River will be reported later in Vol. II to confirm or adjust these preliminary considerations of regional requirements as applied at Ames. Again, these results represent summer streamflow conditions, and winter requirements may be greater.

The data contained in Tables 18 and 19 can now be combined to illustrate the regional differences attributed both to low-flow variations and temperature. Only the normal 85% treatment level (as accepted by the Federal Water Pollution Control Administration) and the 7-day, 10-yr low-flow values are combined in this discussion of combined effects (Grounds, 1967). The low-flow values selected from Table 15 represent the better of the intermediate size streams and the large streams. The population equivalents that can be accommodated per square mile of drainage area can be evaluated using the data in Tables 15 and 19. The results are tabulated in Table 20, and show that the differences among the three regions become even more pronounced when the combined effects are evaluated. In general, there is a 20- to 30-fold difference between Regions I and III in the permissible values of PE per square mile of drainage area. This analysis assumes, of course, that summer or early fall low-flow conditions are controlling.

4. Summary

This study has shown that the low-flow characteristics of Iowa streams, including both magnitude and frequency of low flows and physical characteristics such as temperature and assimilative capacities, will play an important role in water quality management in Iowa. The combination of all of these factors means that in Region III the difference in ability to assimilate effluents discharged to the streams is 20 to 30 times less than that of Region I, for streams of comparable drainage areas. Although preliminary in scope and based on assumed average conditions for midwestern streams, the results show that municipalities in Region III face an increased economic burden if high water quality standards are

Table 20. Population equivalents accommodated per square mile of drainage area at the 85% treatment level[a]

			Permissible values of PE per sq mi			
			Lower boundary value of discharge[b]		Upper boundary value of discharge[b]	
Region	Stream size	f ratio	csm	PE per sq mi	csm	PE per sq mi
I. Ideal	Intermediate to large	2	0.04	85	0.10	210
		4	0.04	180	0.10	455
II. Good	Intermediate to large	2	0.01	17	0.06	100
		4	0.01	33	0.06	200
III. Poor	Intermediate to large	2	0.002	3	0.01	14
		4	0.002	6	0.01	28

[a]Computed using data from Tables 15 and 19, for summer or fall conditions.

[b]Range of magnitude of low-flow discharge shown in Figs. 13-16 and Table 15.

established and enforced. Many of these municipalities will be discharging effluents into essentially dry streams when 7-day, 10-yr low flows prevail. The same, physically unequal burden may result in the smaller drainage areas in Region II.

The overall magnitude of the state water pollution problem as related to stream water quality can also be expressed in terms of population distribution among the regions. The state was subdivided, with 32 counties being assigned to Regions I and II. If Des Moines and Lee Counties are also placed in these regions (since they border the

Mississippi River and the lower Des Moines River and also are in an area of high annual runoff amounts) then 34 of the 99 counties in Iowa are in Regions I and II. According to the 1960 census data (U.S. Bureau of Census, 1963), there were 2,757,537 residents in the state. County population values were tabulated to show that 1,201,344 residents, or 43.65% of the total, resided in Regions I and II. Thus, about 44% of the population is contained in the one-third of the state in which low flows are more ideal, and 56% reside in the southern and western two-thirds of the state in which low flows are most deficient. This indicates that the population density and resultant stress on the streams is higher in the east and northeast part of the state. Because this region has higher assimilative stream capacities, this is a desirable factor in terms of maintaining a statewide balance in levels of stream water quality.

In addition, 15 of the 25 cities having more than 10,000 population are located in Regions I and II. These 15 cities had a total population of 558,173 of the 25 city total of 1,052,079; this shows that one-fifth of the residents of the state live in large municipalities located in Regions I and II. Therefore, it can be concluded that the municipal stress on Iowa streams is placed in the regions which can best sustain it. This confirms that the imbalance which exists physically among the three regions (in terms of assimilative capacity) is offset by the higher population density and added municipal stress in Regions I and II.

The general ability of the streams in Region II to assimilate wastes from large municipalities can be illustrated using the Cedar River at Cedar Rapids. The population of Cedar Rapids was 92,000 in 1960, and the 1965 mid-decade census value was 104,000. At the 85% treatment level indicated in Table 19, then the estimated dilution requirements vary from 0.30 to 0.60 cfs per 1,000 PE. For the domestic treatment requirement, neglecting the industrial requirement, then 30 to 60 cfs would presumably be sufficient. Schwob (1958) reported a 7-day, 10-yr low-flow value of 306 cfs, which is 5 to 10 times the needed quantity. Insofar as maintaining water quality at minimum levels throughout the state, Regions I and II can accommodate increased urban population growth and industrialization much easier than the municipalities in Region III. In regard to uniform water quality standards for Iowa streams, communities and industries in Regions I and II have a substantially brighter future in being able to maintain the established standards at a reasonable cost.

For more equitable consideration of the differences in low-flow characteristics among the three regions, consideration of a warm water coarse fish category, in addition to the cold water and warm water game fish categories, might be suggested, with a minimum of 3 mg/1 DO. Such a category could be placed uniformly across Region III, or at least in the recognized assimilative reaches downstream of water pollution control plants. Inspection of Table 18 data shows that this would increase the available DO from 2.9 to 3.9 mg/1, which would offset the temperature variations between Region III and the others. This would eliminate also the 50% increase in required dilution water as shown previously in Table 19. A second alternative could also be suggested, to recognize the imbalance between Region III and the other two. This would involve a modification of the selected frequency for which the stream water quality standards and related criteria are to apply. The 2-yr, 7-day low-flow magnitude might be designated in Region III, with the 10-yr, 7-day low flow applying in Regions I and II. Economic implications of these water quality levels and modified frequency categories need to be evaluated carefully to ascertain if the changes would be merited.

E. Additional Study of Low-Flow Characteristics of the Skunk River

1. Availability of basic data

The preliminary study of statewide low-flow characteristics placed the Skunk River basin in Region III, the region having the poorest low-flow characteristics. The published data (Schwob, 1958) also indicated that the low-flow characteristics of the upper Skunk River basin at the single long-term gaging station near Ames (315 sq mi) were very poor, with recorded periods of zero flow.

An additional 14 yr of streamflow data were available at the end of the 1967 water year (1953-1967) to add to the base period used by Schwob (1934-1953). This permitted the drought years of the 1950's to be included in an analysis of low-flow magnitude and frequency. An unbroken record of 34 yr (1934 through 1967) for the gaging station near Ames was used in the current studies. In addition, streamflow data were available for two additional stream gaging stations: (1) the Skunk River below Squaw Creek at Ames (556 sq mi, period of record 1953-1967) and (2) the Skunk River near Oskaloosa (1635 sq mi, period of record 1949-1967). Data for all three stations permitted making a detailed study of the magnitude and frequencies of low flows in the upper Skunk River basin, upstream of Oskaloosa.

2. Computer analysis of daily discharge data

Daily discharge data were tabulated and data cards punched for the period of record at each station. A computer program (LOFLO ANALYSIS) was developed for processing daily streamflow records for low-flow analysis, initially for an IBM 7094 and subsequently used on the IBM System/360 Model 40, 50, and 65 of the Iowa State University Computation Center. A maximum of 15 yr of daily discharge data could be processed in a single run, necessitating multiple runs for longer periods of record. The program, once data are read in, prints out the daily discharge record in tabular form by water year to provide a check on the input data. An algorithm was written and incorporated in the computer program that summed the daily discharge data for the desired or specified number of consecutive days, then searched the record for the lowest, next lowest, etc., volume of discharge and subsequently computed the unit area discharge as well as the indicated total discharge. Periods of 1, 3, 7, 14, 30, 60 and 183 days were included in the analysis. Because both summer and winter seasons were of interest, the program permitted computation and extraction of an optimum number of values for each water year so that minimum flow values would be included for both seasons. For instance, 60 3-day values were computed for each year of record, decreasing to 4 60-day values.

After several preliminary trials, it became evident that extraction of minimum annual values would be simplified by dividing the searching period at or near April 1 of each year. Many low-flow periods commence naturally in late fall, extending frequently from September into the winter months of the next water year. Seldom does a stream, however, fail to exhibit a rise in stage and discharge in late March or early April, from either snowmelt or spring rainfall. In selecting April 1 as a break point, extraction of annual and seasonal values is greatly simplified. The printed output included the date at which the period ended, the total volume of flow for the selected period of consecutive days, the average discharge for this period, and the unit area discharge (cfs per square mile, or csm).

3. Selection of summer and winter low-flow periods

The use of low-flow magnitude and frequencies in stream water quality studies necessitates differentiating between summer and winter periods. High air and water temperatures in the summer establish one type of physical environmental conditions for the stream; low air and water temperatures in the winter, accompanied by ice cover, establishes a second type. Therefore, the two seasons were included in the analysis of low-flow data in addition to the annual minimums.

The mean monthly air temperatures recorded at Des Moines and at Ames were used in determining an average winter season, representing a period of ice cover, low temperatures and reduced biological activity. These data are listed in Table 21. The daily discharge data were also inspected to note the average date of spring ice breakup by increasing daily discharges. The winter season was established for the purpose of this study as the period extending from December through March, a 4-month period. Late November periods are indirectly included in this

Table 21. Monthly air temperature data for Des Moines and Ames, Iowa[a]

Month	Monthly air temperature, deg F Des Moines Minimum	Maximum	Average	Ames Average
January	12.5	30.1	21.3	20.0
February	15.9	33.9	24.9	23.9
March	25.8	44.1	35.0	34.2
April	39.1	60.6	49.9	49.1
May	50.7	72.8	61.8	60.5
June	61.2	82.6	71.9	70.2
July	65.6	88.3	77.0	74.8
August	63.6	85.4	74.5	72.7
September	54.1	77.6	65.9	64.3
October	43.0	66.4	54.7	53.3
November	28.3	47.5	37.9	36.7
December	18.1	34.9	26.5	25.1
Annual	39.8	60.4	50.1	48.8

[a]Source: Shaw and Waite (1964).

winter period, since a low-flow period ending in early or mid December would have started in November, depending on the period of days involved, and normally these values were included in the winter period.

4. Detailed analysis of low-flow data for the upper Skunk River basin

a. Average discharge values The primary stream gaging station for purposes of water pollution control at Ames is the gaging station located just downstream of the confluence of Squaw Creek with the Skunk River. The station is located 0.37 mi upstream of the outfall of the Ames water pollution control plant. The discharge measured at this station represents the dilution water available for stream water quality control at and downstream of Ames. The short-term record at this station (1953-1967) can be analyzed and compared with the longer records at the upstream station at Ames and the next downstream station at Oskaloosa.

The average discharge of each of the three stations was determined for the common period 1953-1967, and for the longer period of record at the other two stations. The values are listed in Table 22, and show that the average discharge per unit of area at each of the three stations is almost equal, 0.42 csm, for the common period 1953-1967. The values indicate also that the average discharge for the longer-term stations, for their respective periods of record, have slightly larger discharges in comparison to the shorter-term record. However, the difference is very small, less than 3 to 4%, and it was concluded that the average hydrologic conditions during the short-term common period were similar to those experienced over the long-term records. The short-term record is therefore a normal period of record, and does not represent a drought predominance as was initially suspected from the frequency of zero-flow conditions.

b. Analysis of unadjusted data at Ames and Oskaloosa The computer output of low-flow data was reviewed and minimum winter and summer discharges were extracted for 3-, 7-, 14-, 30- and 60-day periods for each station. Tabulated values of the annual minimum discharges for both seasons are included in Appendix A. Both ending dates and the discharge are given for each year of record. The tabulated values and plotted data will be discussed in this section.

The tabulated data for the long-term station upstream of Ames (315 sq mi) show that the drought years experienced in the 1950's replace the 1930's as the most severe for minimum flows, both for summer

Table 22. Average discharge of the Skunk River at three gaging stations[a]

Period	Station	Drainage area, sq mi	Average discharge, cfs	Average discharge per unit drainage area, csm
1953-1967	Skunk River near Ames	315	131.9	0.419
	Skunk River below Squaw Creek	556	234.8	0.422
	Skunk River at Oskaloosa	1,635	693.6	0.424
1949-1967	Skunk River at Oskaloosa	1,635	714.0	0.436
1933-1967	Skunk River near Ames	315	137.6	0.437

[a]Computer analysis of published data of U.S. Geological Survey (1968).

and winter conditions. For 4 yr of the 34, zero flow has been experienced for periods up to 7 days; for 1 yr of the period of record zero flow extended to a period of 30 days. Also significant is the fact that for the Skunk River below Squaw Creek, upstream of the point of effluent discharge, zero flow has been recorded for 5 yr of the 15 yr of flow record, for consecutive day periods of 3, 7, and 14 days. For 4 yr of the period of record, flows have been zero or almost zero for periods up to 30 days. The extracted low-flow values were plotted and curves of best fit drawn, following the techniques of Schwob (1958). All data and low-flow frequency curves are included in Appendix A.

It was observed that frequently the low-flow discharge at the downstream station was less than that recorded at the upstream station, despite the increase in drainage area from 315 to 556 sq mi as Squaw

Creek joins the main stem of the Skunk River. Groundwater studies (Backsen, 1963; Versteeg, 1968; Sendlein and Dougal, 1968) have shown that the sand and gravel aquifer in which the city well field is located is interconnected through buried channels with the alluvium in the present day valley. Observation wells lying near the Skunk River respond both to the drawdown by pumping and to flood stages in the river. Thus, it is evident that during low-flow periods the Skunk River becomes an influent stream as municipal withdrawals at the well field deplete both the groundwater storage and the interconnected surface water source. All of the used water of the community is discharged downstream of the lower gaging station as effluent from the water pollution control plant.

Inspection of the low-flow record at the Oskaloosa gaging station, located some 75 mi downstream of Ames, indicated that low-flow discharges were much greater in magnitude, both in csm and cfs, than at Ames. With the magnitude of low-flow discharge at the stream gaging station upstream of the outfall at Ames receding to 1 cfs or less every other year (2-yr frequency), it was obvious that the reach of river downstream of the water pollution control plant was benefited by the discharge of effluent. To better illustrate the variation of low flows in the reach downstream of Ames, a modified frequency analysis was introduced.

c. Modified frequency analysis including effluent discharge The records of the Ames water pollution control plant were used to obtain the average daily flow at the plant for the previously tabulated natural low-flow values, for the period 1953-1967 at the downstream gaging station. This procedure was selected as a shortcut procedure of obtaining the combined flow of stream and effluent discharge, in comparison to the more correct procedure of combining all days of record and reanalyzing the entire period. In addition, the method used by Schwob (1958) was adopted for extending the short-term data at the downstream station at Ames and the station at Oskaloosa. This method involves reestimating order numbers for the short-term record in conjunction with occurrences related to the long-term record. Both short-term records were adjusted in this manner. Because the same years of the period of record coincided at each station for the same critical low-flow periods (in providing the minimum low flows), the method appeared reasonable. Results of the modified long-term frequency analysis to represent low-flow conditions downstream of Ames and at Oskaloosa are also included in Appendix A. The plotted data and frequency curves for the combined flow downstream of the water pollution control plant at Ames illustrate the stabilizing effect of effluent discharge on the low flows. The Skunk River at Oskaloosa also has a stable low flow in the winter season, but the period of record has produced some exceptionally low discharges in the summer period.

Regional analysis of both summer and winter low-flow data was accomplished by plotting the 2-, 5-, 10-, 20- and 40-yr recurrence interval low flows versus drainage area, for 3-, 7-, 14-, and 30-day periods. Arithmetic plots gave the most meaningful comparisons, and the results for the 7-day period (summer and winter) are included in Figs. 17 and 18. The remainder of the data is included in Appendix A. Results of the several frequency analyses are summarized in Table 23. The results (using historic values) at the outfall of the Ames water pollution control plant will be modified in the future since the minimum

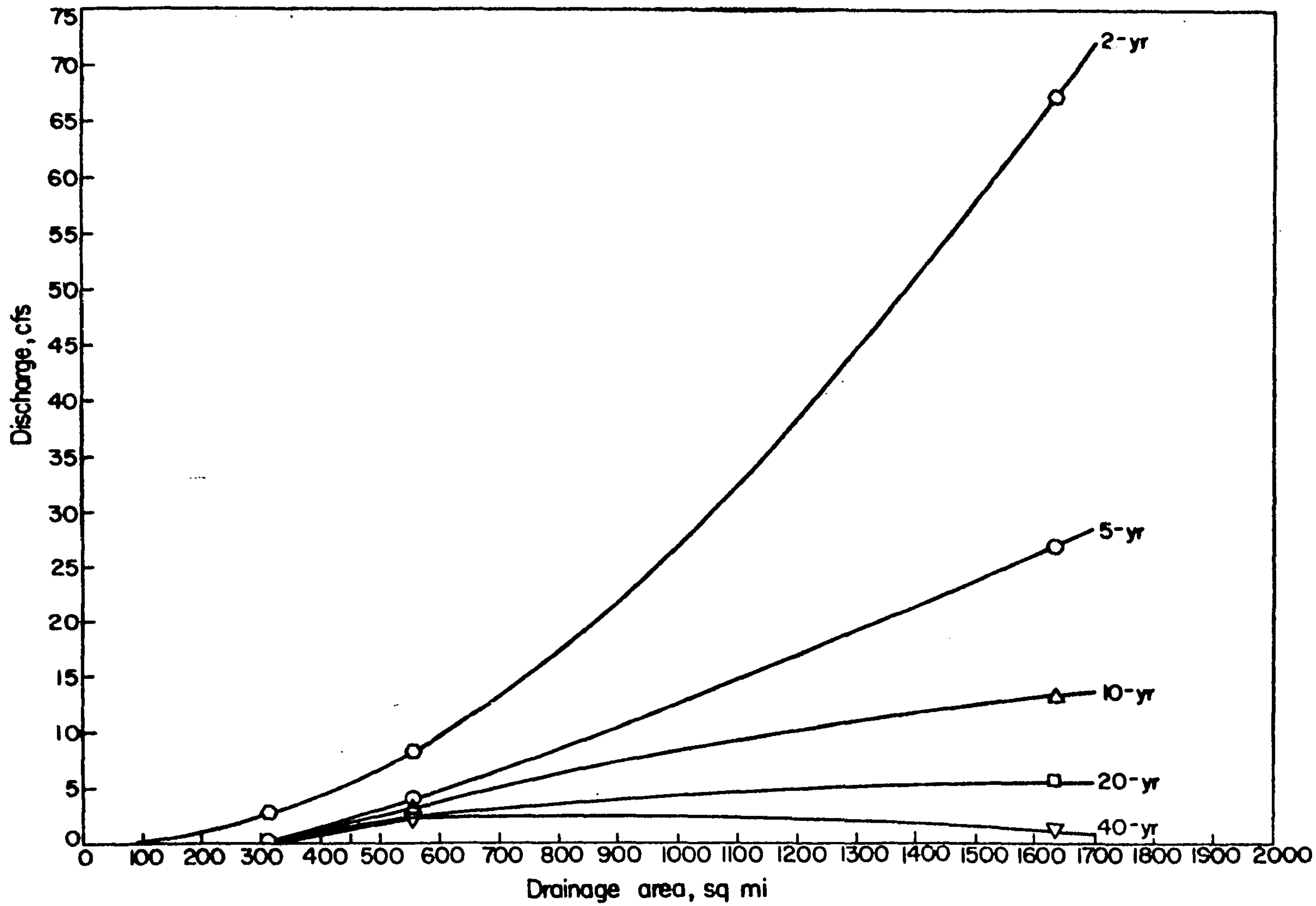

Fig. 17. Regional low-flow characteristics of the upper Skunk River basin for the 7-day periods, summer season, April through November.

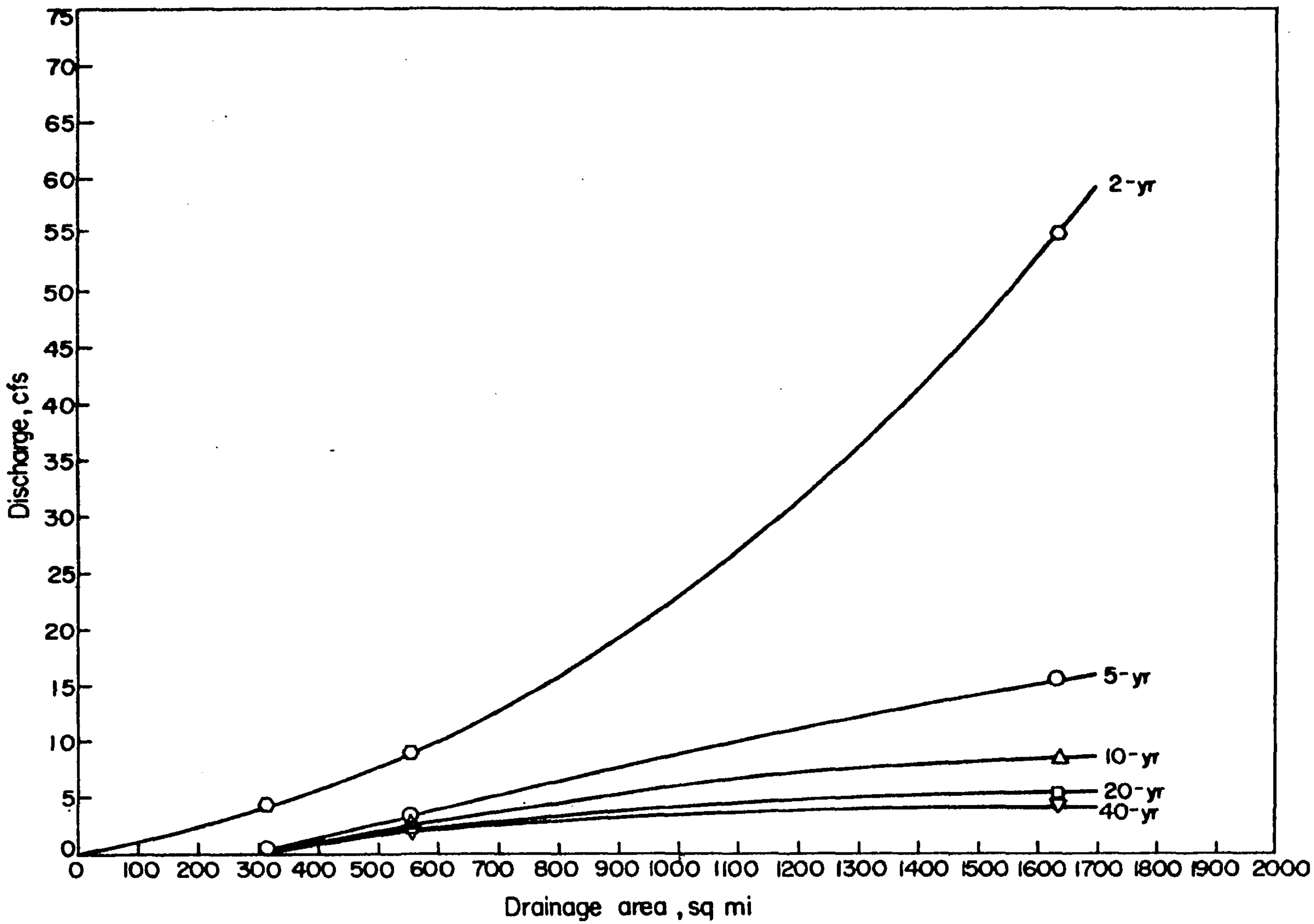

Fig. 18. Regional low-flow characteristics of the upper Skunk River basin for the 7-day periods, winter season, December through March.

Table 23. Historic, modified low-flow characteristics of the Skunk River at five locations, for 7-day periods, based on the period 1934-1967[a]

Season	Recurrence interval, years	Low-flow discharge in cfs for indicated station and frequency				
		(1) Near Ames, 315 sq mi	(2) Below Squaw Creek, 556 sq mi	(3) Below Ames WPC Plant, 557 sq mi[b]	(4) At Colfax, 800 sq mi	(5) Near Oskaloosa, 1,635 sq mi
Summer	2	2.5	4.0	8.3	17.3	67.0
	5	0.22	0.40	4.1	8.5	26.7
	10	0.03	0.08	3.2	6.4	13.3
	20	0.005	0.01	2.7	3.7	5.5
	40	0	0	2.3	2.5	1.4
Winter	2	4.2	2.0	6.8	15.6	54.8
	5	0.47	0.01	3.3	6.4	15.3
	10	0.086	0	2.7	4.5	8.4
	20	0.01	0	2.4	3.4	5.3
	40	0	0	2.2	2.8	4.0

[a]Summarized from data included in Appendix A and Figs. 17 and 18.

[b]Note: Historic results will be further modified in the future at the outfall station since the minimum effluent discharge becomes the minimum streamflow.

streamflow at the outfall will be the minimum effluent discharge. This latter value increases every year as the population of Ames increases.

5. Summary

For the 2- and 5-yr recurrence intervals, as indicated in Figs. 17 and 18, there is a tremendous increase in low-flow discharge with an increase in drainage area. The increase amounts to almost 1 cfs per mile of river between Ames and Colfax (a 30-mi reach), for both summer and winter seasons, at the 2-yr frequency level. This trend holds true for both summer and winter seasons, and for all consecutive periods of days, 3 through 30.

However, for some of the higher recurrence intervals, this increasing trend disappears. At the 20- and 40-yr recurrence intervals, for 3- to 14-day periods, an actual decrease in summer low-flow discharge has been experienced. Because the lowest flows of record occurred during the same period of drought in the 1950's, this loss in the downstream direction represents the effect of evapotranspiration and possible groundwater influent conditions. Analysis of the low-flow data showed that 2 yr of record, 1956 and 1957, provided the low discharge values for the 20-yr and 40-yr plotting points, thus influencing the curve fitting. Examination of the daily flows for these 2 yr, which were the most severe for many central and northern Iowa streams, indicated that there was little or no spring increase in discharge in 1957. Therefore, it is concluded that the alluvial surficial aquifer in the broad valley became exhausted early in 1957 following the dry 1956 period. This lack of spring replenishment deprived the river of its normal source of base flow and a transmission loss through evapotranspiration and/or influent seepage caused the flow at Oskaloosa to be less than the effluent that was discharged at the Ames water pollution control plant.

The fact that the 2 yr of minimum low flow are consecutive (1956 and 1957) implies that the two events are not necessarily independent. This means that the use of annual data assuming independent events is not strictly correct in this instance, and the return interval for the second lowest figure possibly should not be considered in plotting the data. The results do indicate that normally a substantial increase in low-flow discharge will occur downstream of Ames, which will be of benefit in water quality management in the upper Skunk River basin. This increase also became evident during tracer dye studies made in a separate phase of the study. This increase offsets to some degree the poor characteristics observed at the downstream gaging station. The effect of (1) well withdrawals on the natural streamflow and (2) effluent discharge on the amount of water in the stream during drought periods warrants close scrutiny in all areas of the state. These additional withdrawals and discharge of effluents can easily influence the low flows recorded at gaging stations, and it may be impossible to obtain representative records of natural low flows for the streams in Region III.

F. Low-Flow Augmentation from Reservoir Storage

1. Proposed allocation of reservoir storage

Because the low-flow characteristics of the Skunk River at Ames are far from ideal in terms of the supply available for water quality control, the possibility of augmenting the natural low flow by using reservoir storage should be considered as an economic alternative to advanced or tertiary treatment methods. The opportunity for reservoir storage for multipurpose use has been studied and reported by the U.S. Corps of Engineers (1964). Two reservoirs are proposed upstream of Ames, the Ames Reservoir on the Skunk River and the Gilbert Reservoir on Squaw Creek. The Ames Reservoir, a multipurpose reservoir authorized by Congress has storage allocated to low-flow augmentation and water quality control (U.S. Corps of Engineers, 1964; U.S. House of Representatives, 1965).

As originally proposed, the conservation pool of the Ames Reservoir had a water surface elevation of 949 ft (MSL). The authorization report listed an allocation of 25,000 ac ft for water quality purposes, with an additional 8,400 ac ft for sediment storage. During preconstruction planning following authorization, the elevation of the conservation pool was increased to 950 ft. If it is assumed that approximately 50% of the sediment inflow will actually be deposited in delta areas within the flood pool, then the total allocation of storage which might be available for water quality purposes is approximately 32,000 ac ft. Both the authorized volume of storage and the maximum which might reasonably be made available were used in determining the net rate of low-flow augmentation from the fixed amount of storage.

2. Determining the net yield of the reservoir allocation for water quality

The net yield of reservoirs in Iowa, as elsewhere, depends not only upon the variability of streamflow but also is influenced by reservoir losses due to evapotranspiration, seepage, etc. Evaluation of the gross reservoir storage requirements in Iowa to meet uniform annual demands has been reported (Dougal and Shearman, 1964; Shearman, 1967). Schwob (1958) has provided estimates of net storage requirements based upon the historical record of low-flow variability, but no estimates of losses or gross storage requirements were made. Data for the upstream gaging station (Skunk River near Ames) were included in these several studies.

Shearman (1967) determined the magnitude and frequency relationships of low-flow events which have occurred in Iowa for the period 1933-1966. Using methods developed by Stall (1964) and Smith et al. (1966) for determining the frequencies of drought periods, net yield relationships and both gross and net storage requirements were evaluated for selected areas in Iowa. The major drought periods, in order of severity of minimum low flows, were (1) the 1950's, (2) the 1930's, and (c) a period in the 1960's. The results indicated that two significant drought periods had occurred since the period used in Schwob's study (1934-1953).

Hydrologic variables including precipitation and evaporation at potential reservoir sites, low flows of record, and reservoir characteristics were included in the two most recent studies (Dougal and

Shearman, 1964; Shearman, 1967). This technique extended the concepts of Stall and permitted the natural occurrence and relationships among precipitation, evaporation, and low flows to be included in the computation of gross reservoir storage to meet specified annual demands. Shearman (1967) obtained relationships for the storage-yield-frequency of selected stream basins for which hydrologic records were available. The study indicated that the most severe drought which occurred in the 1950's approached if not exceeded the estimated 50- to 100-yr frequency level.

The results of these several studies were reevaluated in this analysis, and estimates obtained for the net yield of the allocated volume of water quality storage in the proposed Ames Reservoir. The results are summarized in Table 24. As might be expected in hydrologic problems, the net reservoir yield depends on the risk probability. The uniform discharge which can be sustained on a 10% chance basis of having inadequate storage (90% dependability level) is twice that for a 1% chance of inadequate storage, or 50 to 60 cfs compared to a 25 to 30 cfs range of outflow.

3. Compatible selection of a design release rate

Previously it was shown that the selection of the period of days and recurrence interval for low flows should be included in the economic dimension as alternative water quality improvement programs are evaluated. Similarly, the selection of a design release rate from the proposed Ames Reservoir for water quality purposes should also be included as a variable in economic studies. Although the volume of storage

Table 24. Estimated net yield-frequency relationship for the proposed Ames Reservoir, Skunk River, Iowa[a]

Estimated recurrence interval, years	Equivalent percent annual chance of inadequate storage	Equivalent level of dependability, percent	Yield factor[b]	Net discharge in cfs for indicated gross reservoir storage allocation: 25,000 ac ft allocation	32,000 ac ft maximum allocation
100	1	99	1.0	25	30
50	2	98	1.2	30	36
25	4	96	1.5	38	45
10	10	90	2.0	50	60
5	20	80	2.5	62	75
2	50	50	3.5	88	105

[a]Analysis of data obtained from Dougal and Shearman (1964), Shearman (1967), and Schwob (1958).

[b]Ratio of (yield for any frequency)/(yield for estimated 100-yr event).

should also remain a variable, the allocation of conservation storage in the authorized project already has been established. Although a decreased storage allocation for water quality control might be considered, the maximum available storage is presumed to be the 25,000 to 32,000 ac ft evaluated in current planning studies.

Compatibility should also be achieved between the frequency for which water quality standards are to apply and the frequency selected for design release rates from the water quality conservation storage in the reservoir. In other words, if the 10-yr frequency level is adopted for water quality standards and the enforcement thereof, then a release rate from the reservoir should be on the same 10-yr frequency basis (90% dependability level). For the Ames Reservoir, this would provide a low-flow discharge of 50 to 60 cfs, with a 10% chance annual risk of having inadequate storage and thus would be compatible with the adopted 10-yr frequency for meeting the established water quality standards for Iowa. It does not appear realistic to establish the release rate at the 100-yr level, for a 1% chance of having inadequate storage, if the state has predetermined that satisfactory water quality can be maintained at the 10-yr frequency level.

G. Appraisal of the Effect of Effluent Discharges on Low Flows

The analysis of Schwob's data (1958) and of the additional record at the gaging stations in the upper Skunk River basin has shown that at most stations in Region III there is little if any streamflow at the level of the 7-day, 10-yr frequency event. Because of the importance of meeting the adopted water quality standards, in terms of enforcement and general desire to satisfy the public's interest in water quality improvement, it appears necessary in Region III to determine the source of low flows at a frequency level of 2 yr or greater. This necessity arises because of two reasons. First, many communities in Iowa withdraw their water supply from aquifers not necessarily connected to the surface stream system (Iowa State Department of Health, 1964). The used water of the community is discharged as effluent following some degree of treatment. This effluent discharge then becomes a physical contribution to the stream, albeit the quality may not be pristine. If stream gaging stations are located along a reach of the stream where the effluent discharge adds measurably to the "natural" low flow, then an artificial flow is superimposed on the data which will be used in low-flow frequency studies. Therefore, some inconsistencies may occur in the data collected in a region if a mix of the two types of stations exists (the economist would speak of "noise in the data").

Second, if communities in Region III and in tributary areas of Region II are penalized for not being able to maintain the adopted levels of water quality standards and criteria thereof, they may elect to use some type of temporary storage facility (such as a modified lagoon storage) in addition to the secondary treatment normally required. This would deprive the stream of the added physical contribution of the effluent discharge. Both quality status and effect upon the stream biological environment should be carefully evaluated before decisions are made to change from a continuous effluent contribution to an intermittent "dumping" of stored effluents.

A series of low-flow measurements were made in the upper Skunk River basin in the fall of 1966 to evaluate this effect. The results are shown in Fig. 19. This season was a typical dry weather period for late fall conditions, and, for one basin in Region III, illustrates the two problems noted above. The effluent discharges can influence the natural low flows that would otherwise occur and also represent a physical contribution. Hydrologists and water quality specialists should exercise care in interpreting the low-flow data collected in regions having poor low-flow characteristics. In Region III of the state, it is doubtful if there are many streams which are not influenced by this phenomenon, since they might otherwise have no flow at all. As magnitudes of effluent discharge increase with the expected increases in urban growth, these effects may become even more pronounced. At Ames, for instance, it has been noted that the minimum streamflow below the outfall will in the future be at least as great as the minimum effluent discharge of the water pollution control plant. Historic data analysis rapidly loses its meaning and importance in view of this phenomenon.

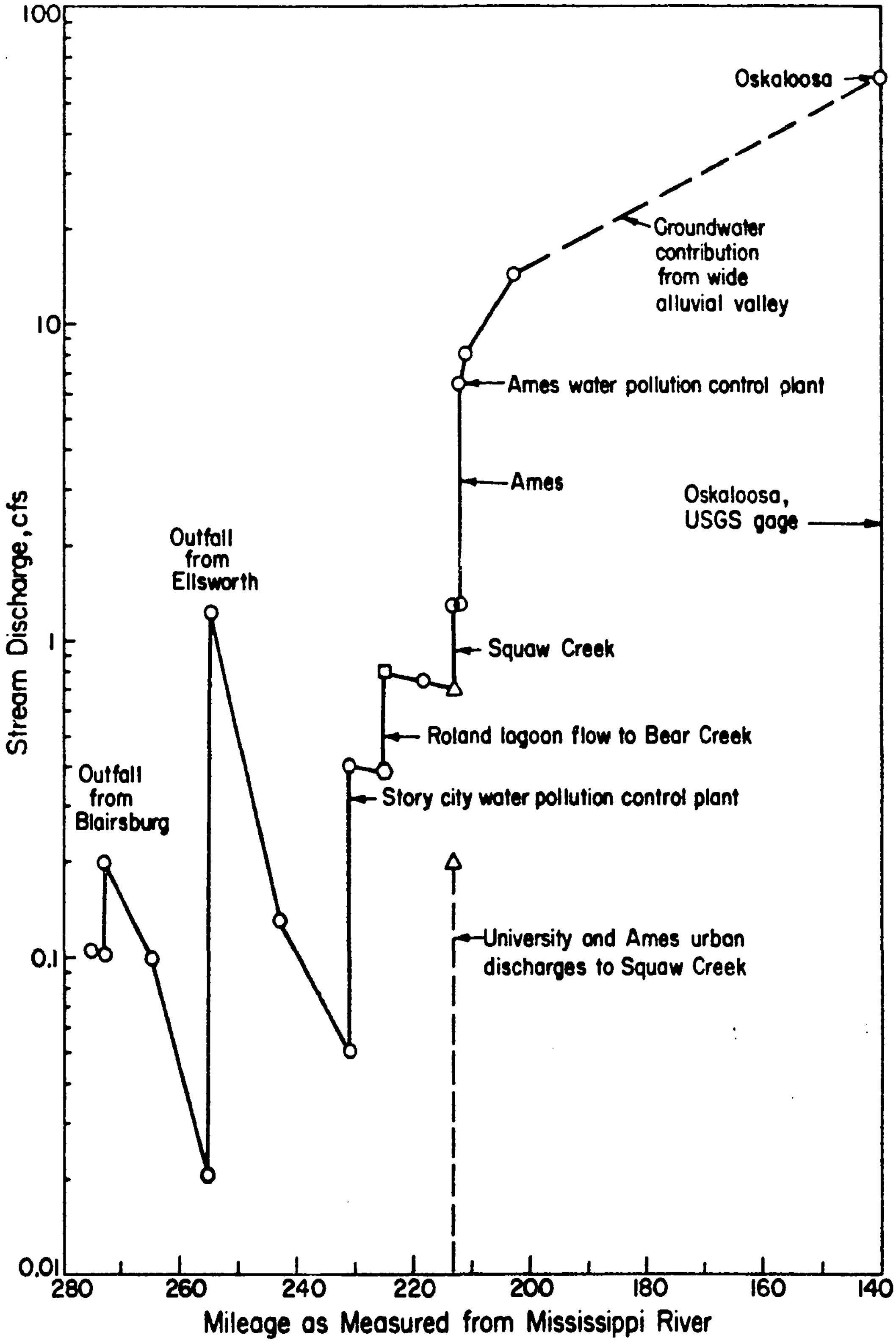

Fig. 19. Effect of effluent discharge from river communities on the dry-weather flow of the Skunk River.

X. THE WATER QUALITY ENVIRONMENT IN THE SKUNK RIVER BASIN

A. General

The physical and socioeconomic characteristics of the Skunk River basin that are pertinent to the case study and related to water quality and the stream system will be evaluated and reported in this section. The general physiographic features of the basin which influence the supply and quality of streamflow will be discussed in the first section. The nature of rural and urban development including the identification of pollution sources within the basin will be outlined in the second section. Detailed population studies and projections for the future at Ames and the four county area in the upper basin will be reported in the third section. The fourth section will be devoted to study of present and future water use and waste water volumes at the principal city in the basin, the city of Ames.

B. Physiographic Features and the Stream System

The Skunk River basin with its long, narrow shape is characteristic of several in Iowa. The overall length is about 180 mi, the average width is 24 mi and the maximum width is 40 mi (see Fig. 9). Its total drainage area of 4,355 sq mi represents 7.7% of the total area of the state. Parts or all of 20 counties are included in the basin (Iowa Natural Resources Council, 1957). Relationships between physiographic features and the water resource are discussed in a report by Twenter and Coble (1965).

1. <u>Glaciation and soils</u>

In the Skunk River basin upstream of Colfax, the region was covered by the most recent glacial advance, the Wisconsin. This area includes Story County and parts of Polk, Marshall, Boone, Hamilton, and Hardin Counties. This "late Wisconsin drift" is an area of youthful topography, with nearly level land interspersed with areas of terminal and recessional moraines having additional and locally prominent relief. Man-made drainage enterprises have been extensive in this area as an aid to agricultural production in a fertile farming region.

A small section of the lower part of the basin was covered by glacial drift of the Illinoian stage and the most downstream part of the basin is associated with the Mississippi River alluvial valley. The remainder of the Skunk River basin, the central two-thirds or more, is associated with the Kansan drift. The topography is much rougher and the streams are in a mature stage of development in this part of the basin. Deep loess deposits overlie the Kansan drift deposits in the areas adjacent to the Wisconsin drift, but thin towards the southeast and east.

Soils in the basin are associated with the broad glaciation categories outlined above. Thus, they are identified with the late Wisconsin drift, the loess covered areas, slopes where the parent glacial material is exposed, and the bottomland and terrace soils (Iowa Natural Resources Council, 1957; Iowa State University, 1965). Sheet, gully, and streambank erosion are noted to be extensive in almost all parts of the basin, but of the greatest magnitude in the loess covered areas.

2. The stream system

The stream system and its general efficiency were described and summarized in the report of the Iowa Natural Resources Council (1957):

> In Hamilton County and part of Story County the Skunk River flows in a youthful and comparatively narrow valley of shallow to moderate depth. In Story County the valley becomes gorge-like with sandstone, shale, and limestone outcroppings along its sides. Immediately above Ames the valley widens rapidly as the river enters a preglacial channel. Below Ames in Story, Polk, Jasper, and Marion Counties the Skunk River occupies a wide and fertile plain having a maximum width of about 2 miles in Polk County. This portion of the originally winding channel has been straightened from near Ames through Mahaska County. The valley bottoms are moderately wide in Mahaska County but are somewhat narrower through Keokuk, Washington, Jefferson, and Henry Counties. The river is very sinuous in Keokuk County but becomes progressively less so downstream. Near Rome, in Henry County, the river enters a postglacial valley and the bottoms are about a quarter of a mile in width. Bedrock is exposed in the bed of the stream and along the valley sides. This gorge continues to below Augusta where the valley becomes wide again and merges with the flood plain of the Mississippi River. Stream slopes in the upper reaches of the Skunk River are moderate to low and tend to decrease on downstream.

Stream slopes vary from 7 to 8 ft per mile in the reach north of Story City in Story County, decrease to about 4 to 5 at Ames, 2 to 3 at and below Colfax, and decrease to a minimum of 1 to 1.5 ft per mile in the lower 60 mi of the river (U.S. Corps of Engineers, 1964). The entire reach of the Skunk River from Ames to the Mahaska-Keokuk County line was straightened during the period 1893-1923 to permit the broad fertile flood plain to be cropped more extensively with less potential of flooding (about 90 mi was straightened).

The stream mileages along the main stem of the Skunk River are listed in Table 25, as summarized from several sources (U.S. Corps of

Table 25. Stream mileage and associated drainage areas of the Skunk River from headwaters to the Mississippi River[a]

Mile	Drainage area, sq mi	Location
275	6.5	Blairsburg, U.S. Route 20
255	54.9	Ellsworth, Iowa No. 175
243	160.	Randall
231	180.	Story City
220	314	Ames Reservoir, proposed dam site
218	315	U.S.G.S. gaging station, upstream of Ames
213	556	Confluence of Squaw Creek with Skunk River
213	556	U.S.G.S. gaging station, below Squaw Creek
212+	557	Ames Water Pollution Control Plant
204	645	Cambridge
192	722	U.S. Route 65
182	800	Colfax, Iowa No. 117
179	1,220	Confluence of Indian Creek and Skunk River
138	1,635	U.S.G.S. gaging station near Oskaloosa
123	1,718	Keokuk-Mahaska County line
113	1,786	Sigourney, Iowa No. 149
93	2,709	Confluence of North Skunk River with Skunk River
90	2,741	Richland, Iowa No. 77
67	2,916	U.S.G.S. discontinued gaging station, Coppock
66	3,202	Confluence of Crooked Creek with Skunk River
43	3,990	Confluence of Cedar Creek with Skunk River
38	4,001	Oakland Mills low head dam
27	4,231	Confluence of Big Creek with Skunk River
12	4,303	U.S.G.S. gaging station near Augusta
6	4,334	Mississippi River backwater at low-flow stage
0	4,355	Confluence of Skunk River with Mississippi River

[a]Summary of data of U.S. Corps of Engineers (1964), U.S. House of Representatives (1965), Latimer (1957), and Schwob (1966).

Engineers, 1964; U.S. House of Representatives, 1965; Schwob, 1966). Drainage areas at key points are also listed (Latimer, 1957).

The general stream system was shown previously in the basin map, Fig. 9. Locational features in the upper Skunk River basin, the area in which major emphasis will be placed in this study, are shown in Fig. 20.

C. Identification of Major Pollution Sources in the Skunk River Basin

Both rural and urban sources of pollution are of general interest in this review, although major attention will be directed towards the urban pollution problem in detailed water quality studies. Basin-wide aspects will be reviewed first, with subsequent attention directed towards field studies and observations in the upper basin.

1. Agricultural, industrial, and municipal enterprises in the basin

The Skunk River basin was noted in the 1957 report of the Iowa Natural Resources Council (1957, p. 1) to be predominantly rural in character with water problems being clearly related to agricultural enterprises. As of 1957, the report concluded

> ...Water supply problems commonly associated with large municipalities and industries do not occur within the basin, and the use of water for waste disposal and recreational purposes is not so important as in the more urbanized portions of the state.....

Evidently these studies were completed prior to the rapid urban growth of several of the major population centers including Ames whose growth has been accelerating in the late 1950's and through the 1960's.

Cropland in the basin decreases from 80% in Story County to 60% in Mahaska County and 54% in Henry County, with the rougher areas having

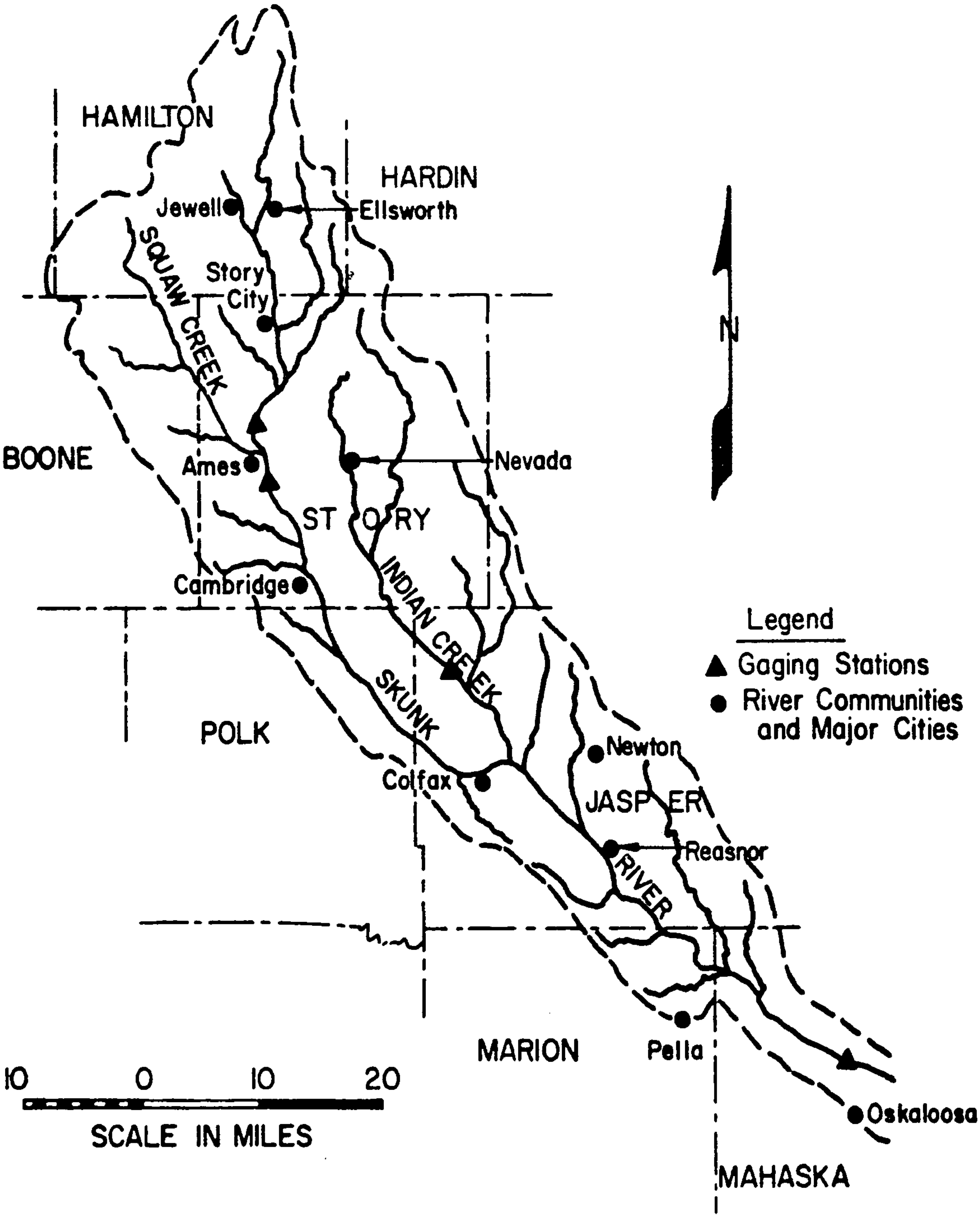

Fig. 20. The upper Skunk River basin above Oskaloosa, Iowa.

more land in pasture and timber. These percentages show that the greatest part of the annual precipitation is used consumptively in the production of agricultural crops. Some irrigation use of water is reported in this "humid area" farming region, but noted to be intermittent and of greatest economic return with high value crops such as seed corn production, etc. (Iowa Natural Resources Council, 1957, 1964; Beer, 1967).

Major manufacturing establishments (over 500 employees) were reported at Newton, Fairfield, and Pella. Electric generating stations were reported at Ames, Ellsworth, Fairfield, Mount Pleasant, Nevada, New London, Pella, Oskaloosa, Salem and Story City, Some of the smaller plants use diesel engines, not requiring cooling water externally. Other major water users (and waste dischargers) were reported at Ellsworth (turkey processing plant), the Iowa Ordinance Plant near Burlington, Fairfield (soybean processing), Sully (cooperative creamery) and Washington (soybean processing).

Rock quarry operations and mineral extraction of sand and gravel deposits constitute the activity of the mining industry in the basin. Limestone is quarried at Ames, near Roland, and near New Sharon for agricultural limestone, road materials, and for concrete materials and aggregates if durable rock is located. Extraction of sand and gravel is extensive at Ames and at Colfax.

Additional major employers in the upper Skunk River basin include (1) Iowa State University, (2) the Iowa Highway Commission headquarters at Ames and (3) the National Animal Disease Laboratory of the U.S. Department of Agriculture which was established at Ames in the early 1960's.

Colleges and universities in the basin encourage an intensification of population for at least 9 months of the year. Those located within the basin are Iowa State University at Ames, Iowa Wesleyan at Mount Pleasant, Parsons College at Fairfield, William Penn College at Oskaloosa; two are located in communities situated on the divide of the basin, Central College at Pella and Grinnell College at Grinnell. Several 2-yr junior colleges now being transitioned into area technical-vocational school systems are located in communities near the Skunk River basin, at Boone, Webster City, Iowa Falls, Marshalltown, and Burlington.

2. Municipal sources of waste discharge

The Iowa Natural Resources Council (1957) reported that there were 73 incorporated cities and towns within the Skunk River basin. Those having more than 2,500 population (1950 and 1960) included Ames as the largest, (27,003 in 1960, 34,826 in special mid-decade census), followed by Newton (15,381 in 1960), Oskaloosa (11,053 in 1960, 11,536 mid-decade), Fairfield (8,054 in 1960, 11,587 mid-decade), Mount Pleasant (7,339 in 1960), Pella (5,198 in 1960, 6,086 mid-decade), and Nevada (4,227 in 1960, 4,840 mid-decade). Washington (6,037) was omitted from this list, but should be included as it is on the north divide, and discharges effluent to the Skunk River system. Of these, only Ames and Nevada are in the Skunk River basin upstream of the confluence of Indian Creek at Colfax, with Nevada being in the Indian Creek basin and Ames located on the Skunk River at the confluence of Squaw Creek. As of 1950, over 65% of the urban population in the basin was located in these seven cities. The incorporated cities and towns in the basin, including the growth trends through 1950, as reported by the Iowa Natural Resources Council, are shown in Fig. 21.

Inspection of Fig. 21 indicates that urban growth is taking place only in the cities where substantial amounts of industry are located and thriving. Smaller communities surrounding the larger population centers receive a "spinoff" benefit, as evidenced in Fig. 21, and experience slight to moderate increases in population. Maki (1965) made an extensive study of Iowa's regional economy and population characteristics that quantitatively confirms the qualitative data shown in the Iowa Natural Resources Council bulletin. In Maki's study, a continuing decline in rural population was forecast, but continued increases were forecast in agricultural production from increased mechanization and efficiency. Urban growth trends depended on continued expansion of the industrial, business, and service sectors. Processing of agricultural products before export from the state was noted to be a major factor in industrial expansion, as was the need for additional mechanization and specialization equipment in the agricultural sector. Increases in both employment and the value of output of production were forecast for durable goods manufacturing with lower increases for mining and non-durable goods manufacturing. The additional emphasis upon manufacturing may tend (1) to increase the industrial water pollution problem, (2) to increase urban growth and (3) to compound the municipal waste problem. The increased mechanization and specialization on the farms may result in increased potential for agricultural pollution through increased use of fertilizers, herbicides and insecticides. Thus, the problems of

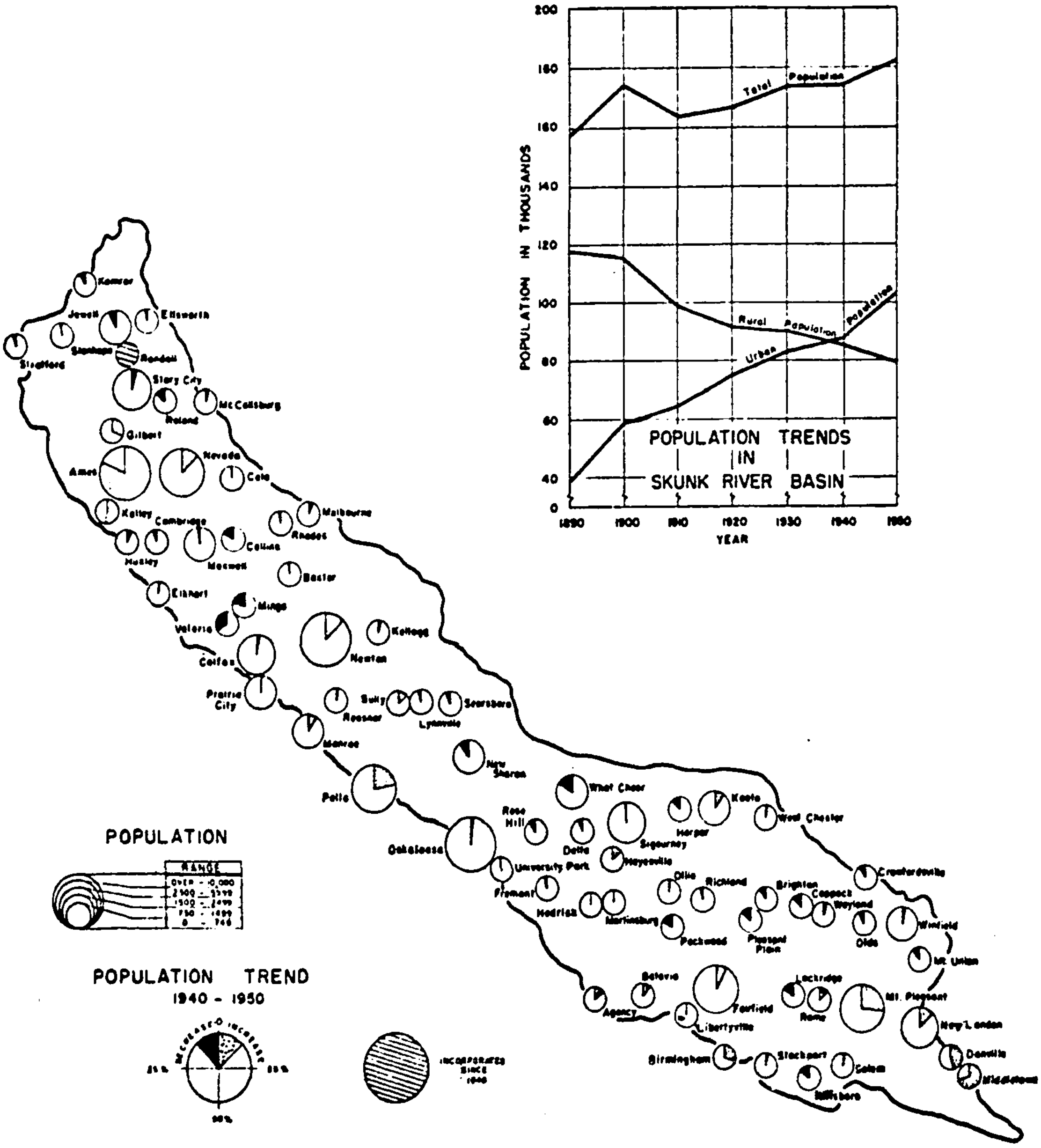

Fig. 21. Incorporated cities and towns in the Skunk River basin, and population growth trends in urban areas (after Iowa Natural Resources Council, 1957).

water quality appear to be increasing in both rural and urban areas, with the decrease in rural households (and farmsteads) being the only point source of domestic and livestock pollution being alleviated (in numbers).

3. Pollution sources in the upper Skunk River basin

Published reports, ground reconnaissance, and aerial maps and surveys were used to identify the general types and locations of pollution sources in the Skunk River basin upstream of Colfax. The Indian Creek basin was excluded from detailed field studies because of limitations on field personnel, funds for travel and field investigations, and time.

a. Sediment as a pollutant Sediment production and delivery to the stream system, as noted by Browning (1967), constitutes the largest mass contribution of pollutants from agricultural sources. However, the sediment yields of river basins in Iowa vary widely, depending upon drainage area, topography, and soil type and cover conditions. Browning noted that the Soldier River at Pisgah, located in an area of rough topography with easily eroded loess soils, produced an average sediment yield of 17 ton per acre annually from a 417 sq mi drainage area in 12 yr of record. The East Fork Hardin Creek near Churdan, located in the level, recently glaciated areas of northern and north central Iowa, has produced only 0.05 ton per acre annually from a 23 sq mi drainage area which contains drainage ditches and extensive tile lines. The Corps of Engineers (1964) reported annual values of suspended sediment of 0.63 ton per acre at Marshalltown for the Iowa River (1,564 sq mi), and 0.28 ton per acre at Boone for the Des Moines River (5,511 sq mi). The Skunk River basin lies between these two basins in somewhat similar topography but with a smaller drainage area. There were no sediment stations in the Skunk River basin prior to 1967, but one was recently established at Ames by the Corps of Engineers, to be operated during flood periods.

Estimates of sediment yield were made by the Corps of Engineers (1964) in the authorization studies for the proposed Ames Reservoir. The data for the Iowa River and the Des Moines River were evaluated, adjusted additionally for drainage area, and a value of 0.6 ton per acre was adopted for the Skunk River near Ames (314 sq mi). This value included a 10% allocation for bed load in addition to the suspended sediment portion collected in sampling. In view of the low production rates for the East Fork Hardin Creek, similar to upstream drainage ditch areas in the upper Skunk River basin, the adopted value appears reasonable. However, if a log-log plot is made of the sediment yield versus drainage area data at Boone and Marshalltown, extrapolation would give a value of 1.5 to 2.0 ton per acre for the Skunk River at Ames. The sediment station at Ames should eventually provide a more accurate value of the suspended sediment level of the study stream.

Although all of the counties within the basin are in organized soil conservation districts, there is little incentive to contour and/or terrace the level to sloping lands in the upper Skunk River basin which are on the Wisconsin drift. Even in areas where terminal or recessional moraines provide localized knolls and sharp slopes, the field investigations indicated no real attempts at soil erosion control. Both ground and aerial inspections indicated light subsoil exposed on these small hills caused by sheet erosion.

Field observations following flood periods have shown that stream clarity returns consistently in from 7 to 10 days, permitting the stream bottom to be observed at least dimly at a 1 to 2 ft depth of flow. As noted in the historical review, fish can survive within this time period. Recurring flood periods would cause longer periods of turbidity than these observed isolated storms, and would stress the fish population additionally.

b. Rural farmstead and feedlot pollution   Farmstead and feedlot pollution are additional sources of agricultural pollution. Field observations in the upper Skunk River basin where drainage ditches and tiling are extensive have shown that most farmsteads discharge septic tank overflow and other farmstead drains to a nearby agricultural drain tile. These were most easily observed during very dry weather periods when there was no contribution from tiles located entirely in farm fields. These waste effluent discharges eventually reach the surface water resource. However, the decrease in rural population and in numbers of farms in Iowa make the farm household waste disposal problem a comparatively minor problem compared to other agricultural pollution sources. The exception is a potential for residual health effects if personal contact by children or adults is made with polluted water at outfalls or in drainage ditches or small streams.

Field observations including two aerial inspection trips indicated that feedlot pollution may be a major problem in the upper Skunk River basin. The largest aspect of this problem is in the area around

Ellsworth where a large turkey growing enterprise has existed since the 1940's, with the central processing plant located at that community. Field inspections have shown that the field areas used during the turkey growing season become packed, are devoid of vegetation, littered with fecal droppings, and the areas in general are conducive to rapid runoff during intense rainfall or runoff periods. The problem is compounded by the fact that turkey raisers tend to select high or sloping ground for drainage reasons.

Livestock feedlots for cattle and swine are believed to be less of a problem since they are scattered and not as concentrated in one region of the basin. No extensive commercial lots were observed during the field investigations, although several large individual cattle feeding operations were noted. Several feedlots at farms located on rolling slopes at the edge of the Skunk River in the region upstream of Ames have open lots that are barren and packed, with a significant potential for rapid runoff during storms. In the reach of the Skunk River downstream of Ames, there are fewer pastures along the stream as the wide bottom lands are extensively cropped.

One livestock feeder at Ames has installed a lagoon for feedlot pollution control, but the lagoon effluent has continued to flow into the recreational impoundment of the Isaac Walton League located northeast of Ames. A bypass tile system purportedly has been installed to prevent further inflow of nutrients which in the past have caused overenrichment and rapid eutrofication of the lake.

c. <u>Use of agricultural chemicals</u> The high percentage of fertile farm lands in crop production, over 80%, with Clarion-Webster soils predominating, encourages high rates of commercial fertilizer application, with related use of herbicides, pesticides and insecticides. Browning (1967) noted that in Iowa fertilizer use increased from 654,000 ton in 1954 to 1.3 million ton in 1964. The estimated quantity in 1980 was 2.5 million ton. Applied nitrogen in any form is converted rapidly by soil bacteria to the nitrate form, which may subsequently leach out if excessive rainfall is received.

Typical applications of fertilizer and other agricultural chemicals to control weeds and pests have been reported for corn yield contests (Des Moines Register, 1967, 1968), with a minimum of 20 acres in test plots. The various reports are summarized as follows:

1. Yield of 215 bushel per acre (Indiana): Spring plowed with 130 lbs nitrogen, 130 lbs phosphate, and 105 lbs of potash per acre applied; planted using as starter fertilizer, 12 lbs nitrogen, 50 lbs phosphate, 25 lbs potash per acre; side dressed in June with 200 lbs actual nitrogen; before planting, 15 lbs insecticide applied by disk; day after planting application of herbicide mixture at 2 lbs Atrazine, 3 lbs wettable powder Ramrod, and 1/4 pint of 2,4-D in 20 gallons of water per acre; plant population 27,000 plants per acre.

2. Yield of 184 bushel per acre (Hancock County, Iowa): Fall plowed with application of 83 lbs phosphate, 67 lbs of potash per acre; before planting, application of 150 lbs per acre of nitrogen as anhydrous ammonia; planted using starter fertilizer of 4 lbs nitrogen, 16 lbs phosphate, 16 lbs of potash per acre; no insecticides, but herbicide applied as 11 lbs Ramrod per acre; plant population, 27,500 plants per acre.

3. Yield of 197 bushels per acre (Delaware County, Iowa): Fall plowed with 30 tons of manure applied per acre and 500 lbs each of phosphate and potash; before planting, 300 lbs per acre of anhydrous ammonia applied; two days before planting, application of 4.75 lbs per acre of Atrazine herbicide; starter fertilizer of 5 lbs nitrogen, 24 lbs phosphate, and 10 lbs potash; 6.5 lbs heptachlor insecticide per acre applied at planting; plant population, 26,000 plants per acre at harvest.

Computations show that if these amounts of nitrogen per acre were diluted in 12 in. of water depth per acre, the concentrations would be equivalent to 60 to 120 mg/l, or if the designated amounts of nitrogen were dispersed into the mean annual precipitation value of 30 in., the concentrations of nitrogen would approach 25 to 50 mg/l. A great potential exists for the leaching of high amounts of nitrate if common use reaches these test plot values. Willrich (1966) has reported on an initial investigation of nitrates in the return flow from agricultural tile drains. Seasonal variations are evident, but application of nitrogen does not appear to coincide with the normal low stream flows which are experienced in late fall and during the winter. During the other seasons, more ample streamflow will be available for dilution if leaching does occur. However, additional research efforts in this area appear warranted.

d. Summary of rural pollution sources These sources (sediment, farmstead, feedlot, fertilizer, and agricultural chemicals) appear to be the major sources of agricultural pollution in the upper Skunk River basin. Because these sources are scattered, field observations and data collection are difficult and time consuming to perform in a consistent and regular basis. Detailed analyses and research in this area were not within the scope of the project, but this general identification is intended to serve as a guide for future research efforts. Because municipal waste problems appeared to have the major influence on water quality during low-flow periods, they were selected for more detailed analysis.

e. Municipal waste disposal facilities Field inspections were conducted to determine the type of water pollution control facility used by each community and the effluent discharge point. These communities and the identified point of waste disposal are listed in Table 26. The use of the stream system for discharge, dilution and assimilation of effluents is illustrated schematically in Fig. 22 for all communities upstream of Oskaloosa.

Many of the smaller communities lack adequate water pollution control facilities. Frequently, discharge to a nearby closed agricultural drain conveniently carries the domestic wastes far from the affected community. A classical example of raw waste discharge and its effect upon the stream environment has been the discharge of untreated wastes at Ellsworth by the turkey processing plant and the municipality. Review of the state report including the field data and additional field observations in 1965-1966 confirmed the undesirable esthetics of such obvious pollution. Presumably this situation existed for some 10 to 20 yr; the 1957 report of the Iowa Natural Resources Council included 1956 information from the State Department of Health which listed no treatment and unsatisfactory conditions at Ellsworth. Purportedly, according to local reports, filing of a lawsuit by a downstream farmer precipitated additional action by the Iowa Water Pollution Control Commission to obtain a time schedule from the community and the turkey processing plant for installation of an anaerobic-aerobic lagoon system. This installation is now complete (1968).

Observation of the raw waste discharge at Ellsworth and data collected by the Iowa Department of Health (1965b) showed that the stream

Table 26. Location of municipal sources of pollution in the upper Skunk River basin

Town or city	1960 population	Receiving stream	Drainage area, sq mi	Identification and notes
A. Skunk River upstream of Ames				
1. Blairsburg	287	County drain to Skunk River	10	Part of town in Iowa River basin. Septic tank overflow to large county drain, 2 mi to Skunk River.
2. Ellsworth	493	Skunk River	55	Outfall of sewer drain about 100 ft upstream of Iowa No. 175; raw sewage flow, 1965-1967.
3. Kamrar	268	D.D. 265 to Mud Lake D.D. 71	10	West part of town drains to Boone River. Septic tank overflow to common drain to D.D. 265.
4. Jewell	1,113	Mud Lake D.D. 71	71	Fairly new waste stabilization pond; raw sewage lift station in shallow valley pumps to pond.
5. Randall	201	Miller Creek to Skunk River	9	Septic tank overflow to county drain to Miller Creek; area around community very flat.
6. Story City	1,773	Skunk River	180	Imhoff tank and trickling filter plant on stream bank.
7. Roland	748	Bear Creek	20	Waste stabilization pond, two cells, fairly new, at edge of stream; city dump across stream.

Table 26 (Continued)

	Town or city	1960 population	Receiving stream	Drainage area, sq mi	Identification and notes
B.	Squaw Creek upstream of Ames				
8.	Stanhope	461	Crooked Creek	7	Old, outdated plant, imhoff tank and slow sand filter.
9.	Stratford	703	—	—	Storm water in east 1/2 town flows to Squaw Creek, 16 sq mi; all sanitary wastes to Des Moines River.
10.	Gilbert	318	D.D. 70 to Squaw Creek	5	Community growing along with I.S.U.; septic tank overflow to common drains to D.D. 70.
11.	Jordan	50	Onion Creek	3	Small unincorporated village east of Boone; septic tank overflow to county drain to Onion Creek.
C.	Skunk River downstream of Ames				
12.	Ames	27,003	Skunk River	557	Complete treatment with trickling filter secondary units.
13.	Kelley	239	Walnut Creek	7	Septic tank overflow to county drains, one north, one east to Walnut Creek (1/2 mi).

Table 26 (Continued)

	Town or city	1960 population	Receiving stream	Drainage area, sq mi	Identification and notes
14.	Huxley	486	Ballard Creek tributary	7	Imhoff tank and trickling filter plant, constructed in 1959.
15.	Cambridge	587	Ballard Creek and Skunk River	29 640	At confluence of Ballard Creek and Skunk River; town located on sandy terrace, septic tanks satisfactory.
16.	Elkhart	260	Unnamed creek to Skunk River	14	Waste stabilization pond, effluent to creek to river.
17.	Valeria	76	Unnamed creek to Skunk River	3	Community about 1 mi from Skunk River; septic tanks overflow to creek.
18.	Colfax	2,331	Skunk River	800	Imhoff tank and trickling filter plant on river bank, upstream 2 to 3 blocks from Iowa No. 117.

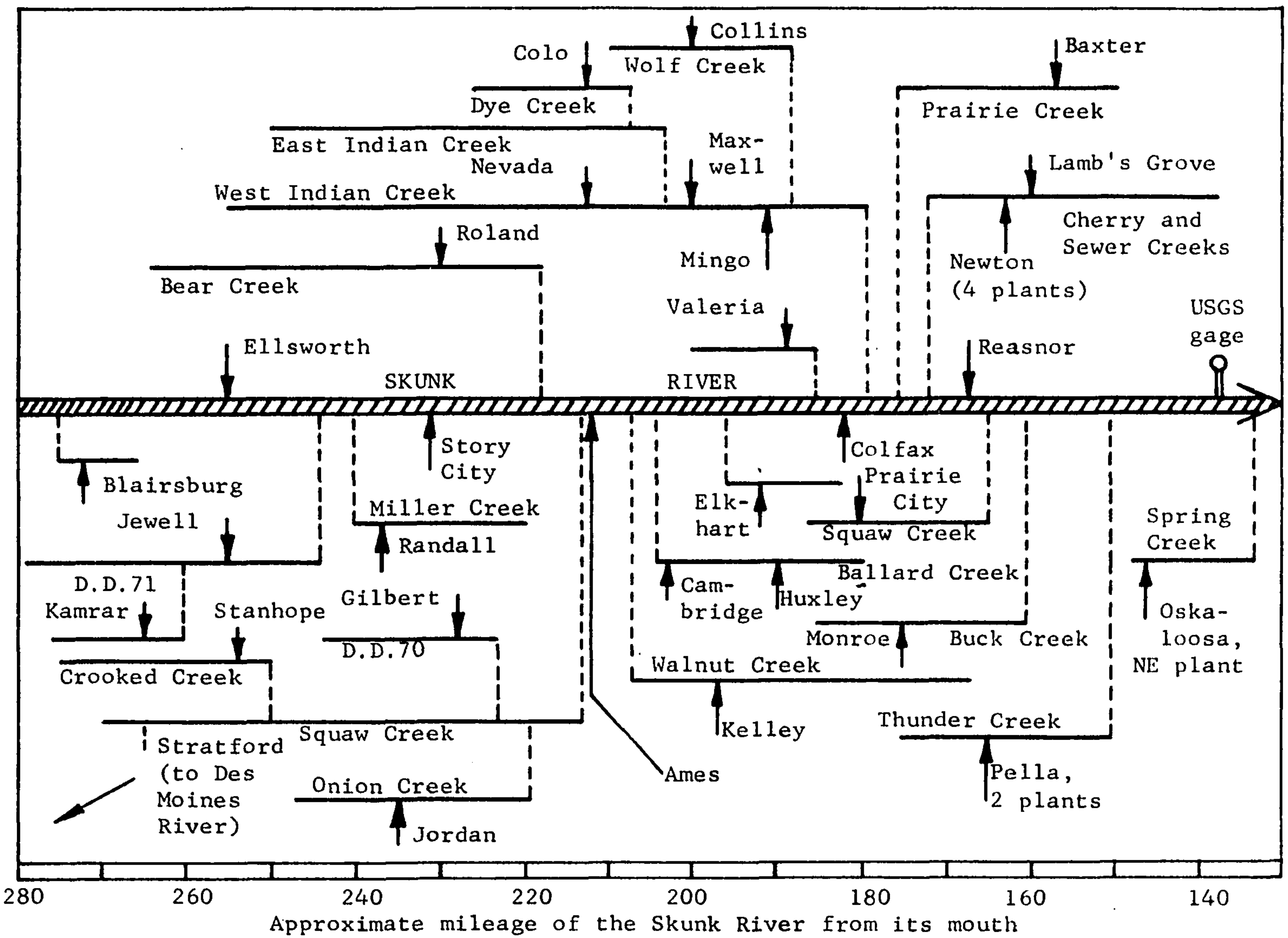

Fig. 22. Use of the stream system for receiving effluents from communities in the upper Skunk River basin.

recovered within about 6 mi, although additional dilution water from the Mud Lake D.D. 71 could also have a beneficial effect. The field observations and the data of the State Department of Health tend to confirm that the municipalities are sufficiently far apart along the Skunk River to permit the streams to recover before the next community is reached, at least in a summer or ice-free period. Thus, few if any interactions may be experienced and each community's effect is independent of the others located more downstream. This implies independency also in the economic dimension, and each individual water pollution control plant can be evaluated for minimum cost separately. The poor low-flow characteristics of the Skunk River also support this independency, since the streamflow at the 7-day, 10-yr low flow will be practically negligible at the separate points of effluent discharge.

f. Suburban problems in the urban fringe area   Suburban development of residential homes outside the corporate limits of Ames has become extensive. A smaller development has taken place southeast of Story City along the bluffs of the Skunk River. Desirable wooded areas and sloping land exists along several tributaries of the Skunk River and Squaw Creek at Ames, and these characteristics are preferred by many homebuilders in comparison to the relatively level open fields being subdivided within the corporate limits.

Eventually these fringe areas will be annexed to the city, as is proposed at the present time, and trunk sewers will be extended to serve the homes. At the present time, however, septic tanks are required by county health regulations. The primary areas of suburban fringe development at Ames are along the river bluffs northeast of the city, northwest of Ames along Onion Creek and Squaw Creek, south of Ames along Worle Creek, and southeast of Ames along tributaries at the bluff line east of Duff Avenue. Numerous suburban waste disposal problems have been encountered, primarily because the tight clay subsoil is not conducive to rapid percolation of septic tank effluent. Health problems have also been encountered, with one outbreak of infectious hepatitis during the study period in the South Duff area.

g. Related industrial pollution problems Most of the industries discharge their wastes to their local community sewers. For example, the National Animal Disease Laboratory at Ames discharges its wastes to the Ames system and contributes to the costs of operating the Ames Water Pollution Control Plant based on both its waste flow and strength. A major trunk sewer was constructed to intercept this new point source of waste, which requires sterilization for disease control prior to discharge to the sewer.

Several industries are located outside of incorporated cities and towns. In the Jewell area there are several mink farms, with one located at the edge of the community. The mineral extracting industries are fairly numerous, consisting of rock quarries in bluff areas and sand and gravel quarries on the flood plains. Two major sand and gravel producers are located north of Ames, and one southeast of the city. One large rock quarry operation is located northeast of the city on a bluff above the river. A second has been opened in recent years north of Roland on a tributary of the Skunk River. A large sand and gravel quarry and processing plant are located at Colfax, north of the city. Water use for washing, dewatering, etc. is regulated by the Iowa Natural

Resources Council through the water permit regulations, and their requirements have included tailings ponds to prevent sediment from entering the nearby streams.

In the Ames area, two occurrences of oil pollution in the Skunk River have been traced to the rock quarry northeast of Ames, where an asphalt plant also is located. A concrete materials producer and ready-mix operation are located at the sand and gravel quarry in southeast Ames. Frequently, washings from the ready-mix vehicles have reached the stream, resulting in discoloration of the water and build-up of a delta at the site.

Various washing and cleanup operations in the vicinity of the physical plant at Iowa State University have caused a fairly steady discharge of effluent to a ditch leading to Squaw Creek near Sixth Street. Observations at low-flow periods have shown the stream to be dry upstream of the city, but the University discharge and other municipal storm and miscellaneous discharges into College Creek cause a definite flow at the U.S.G.S. gaging station at Lincoln Way. Therefore, it appears that zero flow may never occur at the station in the future, although upstream of the city the stream may be dry.

Several research activities involving the use of radioactive materials are located at Ames. The federal Atomic Energy Commission in cooperation with the Institute of Atomic Research of Iowa State University has a reactor unit northwest of Ames on the bluffs above Onion Creek and Squaw Creek, and additional facilities on campus. The College of Engineering has a small reactor for educational and research purposes on campus.

These observations indicate the typical problems of maintaining stream water quality in an urban environment when industrial and municipal activities are scattered and in addition several streams are involved. Control and enforcement of water quality standards will require close surveillance if accidental discharges of wastes and/or deliberate encroachment of water quality is to be prevented. Major control of industrial pollution will remain with the cities and communities which can offer combined treatment facilities for the degree of wastes produced to date. The joint facilities constructed at Ellsworth illustrate this cooperative role.

h. Summary The primary urban stress on the stream system of the Skunk River as related to water quality control will be at Ames. The water pollution control plant, constructed and placed in operation in the early 1950's, was reported adequate by the Iowa Natural Resources Council in 1957. However, the rapid urban growth in the late 1950's and through the 1960's has overloaded the plant (Young et al., 1969). The Iowa Water Pollution Control Commission (1967) listed the Ames plant as needing expansion by 1972. Because of the rapid population growth and the exceedingly poor low-flow characteristics of the receiving stream, it was determined that the most meaningful research results would be obtained for the limited research budget and personnel allocation by concentrating on the municipal water pollution problems at Ames and in the reach of stream below the city. River conditions at and downstream of Ames therefore took priority in the remainder of the study.

D. Population Characteristics and Projections in the Upper Basin

1. Importance of population in water resources studies

Determining the response of the stream environment to man's activities requires a knowledge of the human resources of the region. Past trends, existing demographic characteristics, and population projections will be studied in this phase of the case study of the upper Skunk River basin. Several projection models were developed for the urbanized area at Ames. Additional examination was made of the population trends in rural areas and in the small towns and cities. For the purposes of the case study being conducted in this water resources region, population projections for the period 1970-2000 were needed. Extension of these projections to the year 2020 might be speculative, but would provide additional knowledge for future planning guidance. This extension could be of particular significance if observed and estimated trends would permit designating more definite planning periods within this total time span.

Both the natural increase in the population of a region (birth rate less mortality rate) and the migration or mobility of that population will influence the regional growth trend. For the United States, the Senate Select Committee on National Water Resources (U.S. Senate, 1960b) reported on population projections (as of 1958) for the period 1960-2000, with additional breakdowns for the individual states and for selected river basins. Both natural population increases and migration estimates were considered in this study. The consistent trend of migration from rural areas to urban and metropolitan regions was noted.

A recent study by Maki (1965) indicated the continuance of this trend in Iowa.

The effect of attitudes on the rate of natural population increases was described in a recent resources report (California Institute of Technology, 1967). The discussions included problems of population growth, mortality control and serious overpopulation in developing countries. Discussion items applicable also to the Skunk River basin study included: (1) national movement from an industrial towards an intellectual type economy and society, (2) the gradual control of population being achieved in such a society, and (3) adequate knowledge of the population growth pattern in specific regions. It was reported that Japan had achieved a nearly stable population through an effective managerial approach to population control (birth control measures). In the United States it was reported that the high rate of national population growth during the 1950's had shown signs of rapid decline, with estimated rates of growth for the mid-1960's being only two-thirds of the former. Net growth rates of 1.7 to 1.8% annually in the 1950's had declined to about 1.1% in the mid-1960's. One pertinent conclusion of the report was the potential adoption by the current generation of the attitude that children are an economic responsibility, thus replacing the age-old concept that children represent social security for the parents' old age.

Ackermann and Löf (1959) in a study of water resources technology noted that the mobility of a population in relocating — where people are and will be — depends on four factors:

1. Location of resources other than water
2. Location of efficient service functions in the economy
3. Geographical residential preferences
4. Political or administrative considerations

Combinations of two or more of these would be even more effective in creating regional differences in population growth, with California being the ideal example. McJunkin (1964) illustrated the effect of the fourth factor in noting the phenomenal growth of Brevard County, Florida, which is the site of Cape Kennedy.

These general concepts relating to natural population increases and population migration provide the framework for making population projections in the upper Skunk River basin. The relative importance of each must be evaluated through analytical studies to permit regional effects to be considered.

2. Analytical techniques for population projections

a. Basic concepts Isaard (1960), in association with G. Carrothers, presented an extensive treatise on the various methods and techniques of population projection. McJunkin (1964) summarized the methods of forecasting populations used by sanitary engineers in making water supply and water pollution control studies. Isaard classified the methods of making estimates as direct or indirect. Direct techniques involve the use of past and current data on population numbers. Indirect techniques require correlation of population numbers to other economic, social and political factors. The latter, indirect technique is the most sophisticated, in which population numbers are associated with other aspects of regional economy.

The direct analytical techniques include

1. Comparative forecasting
2. Extrapolation methods
    a. graphic techniques
    b. use of mathematical functions
3. Ratio and correlation concepts
    a. ratio to total population
    b. ratio to population components
    c. regression analysis
    d. covariance analysis
4. Growth composition analyses
    a. national increase methods
    b. inflow-outflow analysis

Concepts of ratios, component methods, and specific rates for the natural increase in population have been developed and used by the U.S. Bureau of Census (1943). The growth composition analyses are the most elaborate of the direct methods.

The difficulties which arise in applying these analytical techniques and in making long-range population projections for the future were summarized by Isaard and further illustrated in the report of the U.S. Senate (1960b). In the latter study, all projections were recognized as extensions of observed trends of national growth patterns. Different assumptions were used, based on birth, fertility, and mortality rates, interstate migration patterns, etc., which provided a reasonable range of population estimates for water resources planning purposes. Achievement of a reasonable range is probably as much as the decision maker can expect to obtain, in view of the uncertainties of the future. The report on population projections at both national and regional levels (U.S. Senate, 1960b) stated that little knowledge existed which justified predicting with confidence more than about 15 yr into the future. Although estimates were made for both 1980 and 2000, the speculative nature of assumptions regarding growth beyond 1980 was emphasized. Purportedly, the state of California has considered 30 yr to be the maximum length of period for which reasonable projections might be made. Too many unpredictable irregularities may arise that alter experienced patterns.

b. Techniques used at the national level   In the national study conducted for the U.S. Senate by both the U.S. Bureau of Census and Resources for the Future, Inc., population projections were prepared using a combination of the component method and the ratio method. The former makes separate allowances for the components of population change and the latter, for the national study, is based on assumptions of the percentage redistribution of population among the states from migration.

The growth composition method, using the inflow-outflow concept applied in the national studies, can be expressed (Isaard, 1960, pp. 27-32) as a mathematical model

$$P_{t+y} = P_t + (aP_t + b) - (cP_t + d) \qquad (97)$$

where

P_t = population at time t,

P_{t+y} = population at a future time, t + y,

a = birth rate during period y,

b = in-migration during period y,

c = death rate during period y, and

d = out-migration during period y.

Ratio methods may be based on ratios to total populations or ratios to population components. As used in the national studies and expressed by McJunkin (1964), simple ratio methods can be expressed as

$$\frac{P_f}{P_{f'}} = \frac{P_i}{P_{i'}} = K_p \tag{98a}$$

where

P_f = population forecast for the study area or component,

$P_{f'}$ = population forecast for the regional area or other base magnitude of a pattern area,

P_i = population of the study area at a selected time, or of a component at the selected time in the past,

$P_{i'}$ = population of the regional area at the selected time in the past, or other base magnitude of the pattern area in the past, and

K_p = a ratio constant.

Regression analysis can be introduced to provide an extension of Eq. 98a beyond a constant ratio to give

$$P_f = aP_{f'} + b \tag{98b}$$

for a regression model, where a and b are constants.

For the 1960 Senate Select Committee report, the Resources for the Future study group introduced a high-, medium-, and low-range concept for all projections. The U.S. Bureau of Census in the same report used a series of four (I, II, III, and IV) fertility assumptions in projecting the population growth of the contiguous 48 states. Regional and state distributions were evaluated using two assumptions regarding interstate migration. For comparative purposes, these are listed below:

1. Fertility assumptions (as measured by the gross reproduction rate, GRR):

Series I: From 1958 to 1975-1980, fertility averages 10 percent above the 1955-57 average (1.79); then fertility declines to the 1949-1951 level (1.54) by 2005-10).

Series II: Fertility remains constant at the 1955-57 average level to 1975-80; then declines to the 1949-51 level by 2005-10.

Series III: Fertility declines from the 1955-57 level (1.79) to the 1949-51 level (1.54) by 1965-70 and remains at this level to 1975-80; then declines further to the 1942-44 level by 2005-10 (1.28).

Series IV: Fertility declines from the 1955-57 level (1.79) to the 1942-44 level (1.28) by 1965-70, then remains at this level throughout the projection period to 2005-10.

2. Mortality assumption: One assumption was used in all four population series, assuming moderate decline in mortality to the year 2000.

3. Net immigration from abroad: Assumed to be 300,000 annually for the nation for all series.

4. Migration assumptions, for projection of state and regional populations:

(1) The average annual amount of migration of the period 1950-58 was assumed to prevail to 1970 and then the average annual amount of migration of the 1940-58 period was assumed to prevail for the period 1970-80.

(2) The average annual amount of migration during the period 1958-80 was assumed to equal one-half of the 1940-58 period.

(3) For the period 1980-2000 a ratio method was used, based on the projections obtained for the 1970-80 period.

The gross reproduction rate, GRR, used by the Bureau of Census is a summary measure of annual fertility. As noted by the U.S. Department of Commerce (1959),

> ...It indicates the number of daughters a group of newborn female infants would have during their lifetimes if the group were subject to the given set of age-specific birth rates and none of the infants died before reaching the end of the child-bearing ages. A rate of 1.00 would represent exact replacement in the next generation....a GRR of 1.54 still indicates a fertility level of more than three children born per woman, a level which may be difficult to maintain over the next 50 years in light of the long-term trend in fertility....

3. Population projections that have been published for Iowa

The net reduction in annual population growth (California Institute of Technology, 1967) from a rate of 1.7 to 1.8% annually in the 1950's to about 1.1% annually in the mid 1960's, indicates that the Series III and IV fertility assumptions may be the most relevant. These implications will be considered in making projections for the case study.

Maki (1965) reported on the growth trend of population in Iowa. Since 1880 the Iowa population has increased at an equivalent rate of only 0.6% annually, whereas the national rate (1880-1960) increased at an annual rate of 1.5%. The difference widened during the decade 1950-60, with the Iowa growth rate decreasing to 0.5% and the national growth rate increasing to 1.8%. It was also noted that Iowa had a higher than national birth rate, which in combination with the low net growth rate indicated a large out-migration of Iowa-born residents. As of 1950, there were 2,029,800 Iowa-born people residing in Iowa, and almost 1,200,000 Iowa-born residents living in other states. The population pyramid presented by Maki showed that this out-migration occurred after the age of 20, meaning that upon receiving an education, Iowa young people were seeking employment opportunities outside of the state.

Population data and projections for Iowa, as collected from several sources, are listed in Table 27. These data reveal several trends and indications, none of which are encouraging for economic growth of the state as a whole. First, the decennial census data show that since 1940 the increase per decade has been only 110,000 or a net increase of 11,000 per year. However, births have ranged from 45,000 to 66,000 annually and deaths from 25,000 to 30,000. Second, the 1966 provisional estimate of the state population, 2.747 million, is less than either the 1958 provisional estimate or the 1960 census figure. The latest provisional estimate also indicates that Maki's projections may be slightly too high. Based on these "less-than-encouraging" statistics, two modifications were computed for the purposes of the case study and included in Table 27. These were introduced for both Series II-1 and IV-1, using as an estimate of the 1970 population of Iowa a value of 2.8 million. The ratio method was used in making the modified projections, with K_p of Eq. 98a being the ratio of the new estimate of the 1970 population of Iowa to the 1970 projection shown in Table 27. Values were rounded to two significant figures and adjusted also to provide uniform annual increments used subsequently in regional projections.

Table 27. Population projections for the state of Iowa as obtained from selected sources[a]

Source and description	1940	1950	1958	1960	1965	1966	1970	1975	1980	2000
	Population in millions for indicated year									
1. U.S. Bureau of Census Decennial census data	2.538	2.621		2.758						
2. U.S. Department of Health, Education, and Welfare Vital statistics						2.747				
3. U.S. Bureau of Census 1958 estimates for U.S. Senate			2.822							
a. Series II-2							3.256		3.790	5.321
b. Series II-1							3.178		3.608	4.934
c. Modified Series II-1 for case study[b]							2.8		3.2	4.2
d. Series IV-2							3.091		3.360	4.065

[a]Source: Maki (1965); U.S. Bureau of Census (1963); U.S. Department of Health, Education, and Welfare (1967, 1968); U.S. Senate (1960b).

[b]Series II-1 and IV-1 modified for case study of upper Skunk River basin using ratio method (see text).

Table 27. Cont.

Source and description	1940	1950	1958	1960	1965	1966	1970	1975	1980	2000
			Population in millions for indicated year							
e. Series IV-1							3.014		3.188	3.744
f. Modified Series IV-1 for case study[b]							2.8		3.0	3.5
4. Maki's 1965 estimates					2.801		2.865	2.938		

4. Regional and temporal characteristics of the population in the upper basin

a. Source of data Population data for the Skunk River basin were obtained from various reports and publications of the Bureau of Census, records of Iowa State University, State Department of Health unpublished information, and from the city of Ames. Drainage area maps were copied from the base maps used by Latimer (1957), so that the percentage of each civil township reported in the census data and contained in the upper Skunk River basin could be ascertained. Although only a small part of Hardin County is involved (less than 20 sq mi in the Indian Creek basin), it was included in the regional analysis for two reasons. It is within the radius of influence (Haynes, 1966) for recreational use of the proposed Ames Reservoir, thus requiring the population to be included in planning of recreation, water use and water pollution control facilities in the region. Second, it serves as an example of growth trends for the more rural counties in central Iowa.

b. Analysis and discussion of the basic data The population data for Ames, Iowa State University, and the four counties associated with basin and reservoir planning are listed in Table 28. Decennial data for all incorporated cities and towns in the upper basin above Colfax are included in Table 29. The rural population data for civil townships located partially or totally in the upper basin and the township area located within the upper basin are listed in Tables 30a and 30b. The Indian Creek basin has been excluded from this analysis, and the data represent the population residing in the 800 sq mi drainage area above Colfax. It should be noted that the rural population data in

Table 28. Population data[a] for four-county area comprising the upper Skunk River basin at Ames, Iowa

Year	Ames and Iowa State University: Ames	Ames and Iowa State University: I.S.U.	Four-county area: Story County	Four-county area: Boone County	Four-county area: Hamilton County	Four-county area: Hardin County
1900	2,422	1,062	23,159	28,200	19,514	22,794
1910	4,223	1,547	24,083	27,626	19,242	20,921
1920	6,270	3,584	26,185	29,892	19,531	23,337
1930	10,261	4,318	31,141	29,271	20,978	22,947
1940	12,555	6,567	33,434	29,782	19,922	22,530
1950	22,898[b]	8,135	44,294	28,139	19,660	22,218
1960	27,003	9,726	49,327	28,037	20,032	22,533
1965	34,835[c]	14,014	(56,150)[d]			

[a]Bureau of Census data, Ames and four-county area; Iowa State University enrollment data from Registrar's Office.

[b]The 1950 census was the first to include students residing within Ames and Story County as local residents.

[c]Special census, 1965.

[d]Estimate by Iowa State Department of Health.

Tables 30a and 30b are for the entire township, and have not been proportioned for the amount of the civil township actually lying in the upper basin.

Inspection of the Ames population data in Table 28 provides the first indication of "noise" in the data. The 1950 census was the first to include students at colleges and universities at their place of school residence. Prior to this they were counted at their home residence.

Table 29. Population trend data for the incorporated towns and cities in the Skunk River basin above Colfax, Iowa[a]

Community	1960	1950	1940	1930	1920	1910	1900
	Decennial population for indicated year						
Ames	27,003	22,898	12,555	10,261	6,270	4,223	2,422
Blairsburg	287	257	276	274	272	241	–
Cambridge	587	573	608	639	739	696	667
Colfax	2,331	2,279	2,222	2,213	2,504	2,524	2,053
Elkhart	260	222	215	218	196	132	–
Ellsworth	493	439	444	405	512	406	319
Gilbert	318	297	226	221	221	235	–
Huxley	486	422	392	362	366	336	–
Jewell	1,113	973	1,051	950	1,090	941	947
Kamrar	268	261	288	286	256	262	223
Kelley	239	244	159	179	192	231	187
Randall	201	202	–	–	–	–	–
Roland	748	687	791	759	829	641	557
Stanhope	461	420	425	425	400	281	297
Story City	1,773	1,545	1,479	1,434	1,591	1,387	1,197
Valeria	76	57	79	57	70	–	–

[a]Source: U.S. Bureau of Census (1963); no data indicates town was not incorporated at that time.

Similarly, the enrollment data at Iowa State University represents fall quarter enrollment. The enrollment tends to drop during the year, from quarter to quarter, and a much lower summer enrollment is experienced. Some of the staff included as city residents undoubtedly leave the city in the summer if their appointments are for the 9-month school year. Because the low-flow studies have shown that the stress on the stream will be in late summer and fall, and again in the winter, use of the fall enrollment student data and the census figures for the city residents (with students included after 1950) will be accepted for water quality

Table 30a. Comparison of rural and urban population in the Skunk River basin upstream of Colfax, Iowa, for the period 1900-60[a]

County and description	1960	1950	1940	1930	1920	1910	1900
	Population for year and category indicated						
Boone County	28,037	28,139	29,782	29,271	29,892	27,626	28,200
Urban population	17,214	16,583	17,193	16,603	17,051	13,885	11,542
Rural population	10,823	11,556	12,639	12,668	12,841	13,741	16,658
Hamilton County	20,032	19,660	19,922	20,978	19,531	19,242	19,514
Urban population	12,504	11,314	10,389	10,525	9,337	8,350	7,357
Rural population	7,528	8,346	9,533	10,453	10,194	10,892	12,157
Jasper County	35,282	32,305	31,496	32,936	27,855	27,034	26,976
Urban population	23,038	18,601	17,220	18,038	13,495	10,739	8,887
Rural population	12,244	13,704	14,276	14,898	14,360	16,295	18,089
Polk County	266,315	226,010	195,835	172,837	154,029	110,438	82,624
Urban population	240,375	191,538	169,195	151,302	134,496	92,676	66,892
Rural population	25,940	34,472	26,640	21,535	19,533	17,762	15,732
Story County	49,327	44,294	33,434	31,141	26,185	24,083	23,159
Urban population	38,779	33,686	22,809	20,184	16,176	12,942	10,138
Rural population	10,548	10,608	10,625	10,957	10,009	11,141	13,021

[a]Source: U.S. Bureau of Census (1963).

Table 30b. Population trend data for rural township areas in the Skunk River basin upstream of Colfax, Iowa, for the period 1910-1960[a]

County or township	Area of twp. in the basin, sq mi	Total rural population in entire township for indicated decennial census year 1960	1950	1940	1930	1920	1910
Boone County		28,037	28,139	29,782	29,271	29,892	27,626
Colfax Twp.*	17.3	546	587	649	564	586	620
Des Moines Twp.	8.8	1,288	1,382	1,394	1,378	1,606	1,557
Dodge Twp.	23.6	799	878	976	933	939	1,085
Garden Twp.*	2.8	540	567	721	774	718	892
Harrison Twp.*	35.2	570	602	693	743	739	747
Jackson Twp.*	36.2	621	632	681	777	805	874
Hamilton County		20,032	19,660	19,922	20,978	19,531	19,242
Blairsburg Twp.	6.0	422	481	518	585	562	516
Clear Lake Twp.	35.2	527	556	629	656	674	771
Ellsworth Twp.	36.3	501[b]	589[b]	932	995	858	938
Hamilton Twp.*	26.2	393	455	531	582	591	748
Independence Twp.	6.5	511	541	555	619	557	558
Liberty Twp.*	36.0	505	532	620	653	755	757
Lincoln Twp.	36.4	541	541	632	694	642	790
Lyon Twp.	32.1	451	481	530	555	568	596
Marion Twp.	35.7	496	530	576	573	626	733
Rose Grove Twp.	6.1	438	532	580	670	637	620

[a]Source: U.S. Bureau of Census (1963); Latimer (1957); asterisked townships have no incorporated communities.

[b]Town of Randall incorporated in 1940 (see Table 29).

Table 30b. Cont.

County or township	Area of twp. in the basin, sq mi	1960	1950	1940	1930	1920	1910
		Total rural population in entire township for indicated decennial census year					
Scott Twp.*	35.3	552	640	719	812	908	926
Webster Twp.*	6.5	356	471	494	626	653	704
Williams Twp.*	8.3	377	467	510	598	561	490
Jasper County		35,282	32,305	31,496	32,936	27,855	27,034
Des Moines Twp.	2.2	798	867	1,026	1,088	1,039	1,229
Mound Prairie Twp.*	6.0	595	604	682	728	892	1,383
Poweshiek Twp.	18.1	632	612	734	720	776	1,013
Washington Twp.	20.3	630	639	666	710	743	739
Polk County		266,315	226,010	195,835	172,837	154,029	110,438
Beaver Twp.	2.3	465	459	699	747	800	494
Douglas Twp.	5.3	621	655	626	752	688	1,640
Elkhart Twp.	27.9	571	638	726	801	832	791
Franklin Twp.	30.5	522	530	560	561	658	633
Lincoln Twp.	2.4	741	716	714	736	747	682
Washington Twp.*	26.6	497	586	659	701	723	750
Story County		49,327	44,294	33,434	31,141	26,185	24,083
Franklin Twp.	31.4	1,245	961	883	1,130	980	1,119
Grant Twp.*	15.3	602	710	619	681	712	725
Howard Twp.	32.8	541	588	631	706	706	754
Indian Creek Twp.	0.7	543	684	628	673	669	796

Table 30b. Cont.

County or township	Area of twp. in the basin, sq mi	Total rural population in entire township for indicated decennial census year 1960	1950	1940	1930	1920	1910
Lafayette Twp.	34.6	594	683	637	656	602	606
Milford Twp.*	11.1	676	754	677	782	677	745
Palestine Twp.	25.4	621	752	686	748	676	842
Union Twp.	29.2	472	532	573	581	510	632
Washington Twp.	26.2	1,822	1,052	1,089	974	834	809

purposes. However, in terms of water supply and maximum demands which normally come in the summer periods, the city of Ames is in a unique position. As the hot summer period arrives, many of the students and some of the staff depart. Therefore, the ratio of peak daily demand versus average day may not be as great as would normally be expected. Similarly, up to late August or early September there will not be the full population equivalent of waste discharge delivered to the pollution control plant. Because summer enrollment has increased substantially during the last decade, this stress relief in the summer may not be of the magnitude experienced in the past. The student enrollment figures in Table 28 represent the total number of undergraduates and graduates (and a small percentage of special students), some of which are also staff of the university, married students maintaining their own households in the city or in married student housing, etc. This means that prior to 1950 some error may be introduced by adding the student enrollment to the city census data to arrive at an estimated total city population. Some students commute from surrounding communities, with a sizeable delegation from the Des Moines metropolitan area. Thus, subtracting the student enrollment from the total census figure for Ames, from 1950 to the present time, may not precisely represent the more permanent city residents (without students). It appeared impossible to eliminate the several sources of noise. With the exception of commuting students in the 1960-65 period, the unadjusted data had to be used in making population projections for the Ames area.

One additional source of noise appears in the data listed in Tables 28-30. Towns and cities periodically annex new areas, and the newly-annexed areas may have contained a considerable number of people who were formerly counted as township residents in previous censuses. Similarly, these suburban fringe areas represent primarily urban residents, and if counted as township residents, they obscure the rural population estimates for farmsteads. In Table 30 the townships in which there are no incorporated cities or towns are noted by an asterisk. However, this does not preclude the existence of small unincorporated villages which can quickly swell a township's population.

c. Population trends at Ames The population data included in Tables 28 and 30 show that Story County experienced the greatest population increase of all the counties in the upper Skunk River basin. The data also show that this increase can be attributed primarily to the growth of Ames and Iowa State University. Because the student enrollment at Iowa State University is a large proportion of the urban population, being 35% in 1960, it may continue to influence the future growth pattern of the community. The census mix between city population and student enrollment can be resolved by establishing three population categories: (1) total city including students, (2) residents without students, and (3) student enrollment. Prior to 1950, university and census data included categories (2) and (3). Category (1) was obtained by adding the other two. Category (2) was obtained for the period since 1950 by subtracting the data obtained for the other two. Additional refinement was obtained by making further adjustment for commuting students in 1960 and 1965 (291 and 585 students respectively). Prior to 1960 the numbers of students commuting was not considered to be sufficiently large to influence the results; in addition, the existence of an "Ankeny campus" during the post World War II days makes exact analysis difficult if not impossible.

The growth trend of each of these three categories is shown in Fig. 23 for the historic period 1900-1965. During the 50-yr period from 1910 to 1960, an almost linear growth trend was experienced. For a linear pattern, the relative rates of growth per decade were 1,630 for student enrollment at the university (Category 3), 2,670 for residents without students (Category 2), and 4,300 for the combined population (Category 1). However, the rapid increase in enrollment at Iowa State University since 1960 and the results of the 1965 special census show clearly that other dynamic influences exist preventing simple linear extrapolation for the future. Additional data and relationships must be obtained and evaluated to ascertain the dynamic growth pattern now being experienced. If adequate projection techniques and causal relationships can be established between state population data and the student enrollment, and subsequently between student enrollment and city population, then projections for the future may be made with a fair degree of confidence.

d. Population trends in the remainder of the upper basin The population trends for Boone, Hamilton, Hardin and Story County (less the combined Ames and Iowa State University population) are shown in Fig. 24. Of the four, only Story County has experienced a consistent growth trend since 1920; the other three have remained quite stable in terms of population. Inspection of the data listed in Tables 29, 30a and 30b and of Fig. 21 illustrates several new growth trends in the region. Whereas many of the smaller communities experienced a decrease

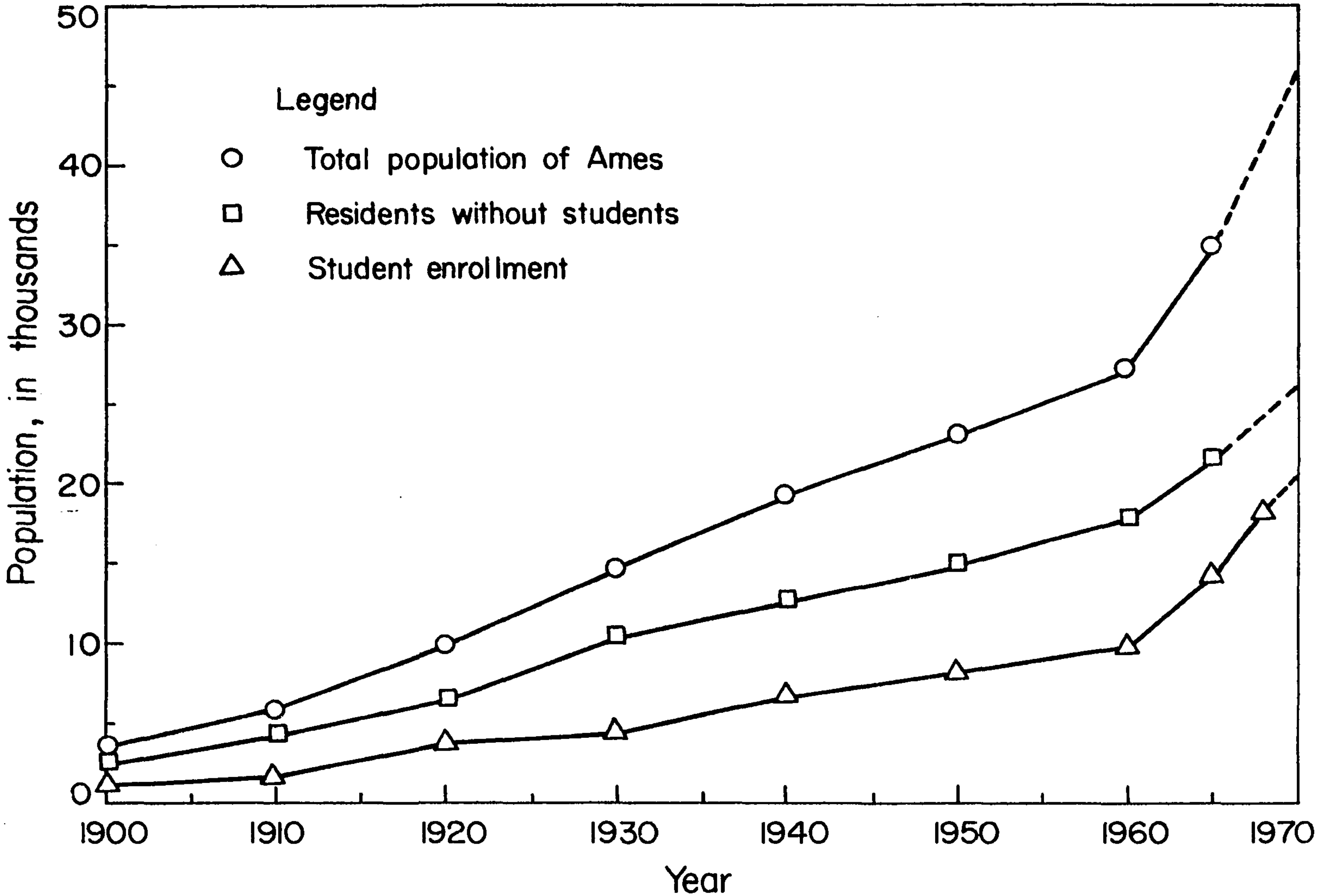

Fig. 23. The historic population trend at Ames, Iowa, including Iowa State University.

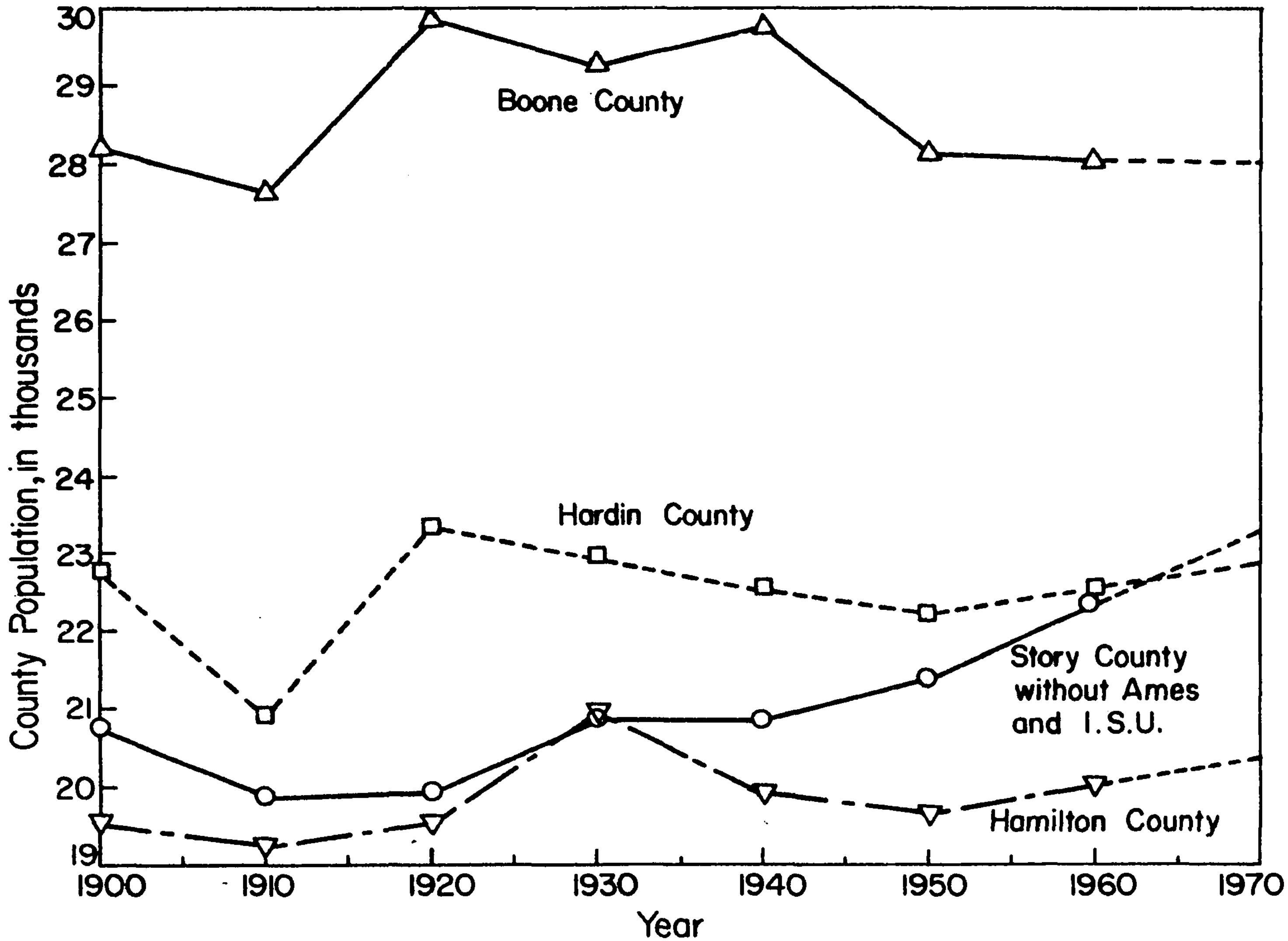

Fig. 24. Historic population trends for the four-county area of the upper Skunk River basin at Ames, Iowa.

in population in the decade 1940-50, almost all of them enjoyed some measure of growth in the 1950-60 period. However, of all the communities listed in Table 29, only Elkhart, Gilbert, Huxley and possibly Story City have experienced a steady rate of growth since 1910. The others have not regained the loss in population since previous population highs were recorded in the period 1910-20.

The most noticeable decrease in population is in the rural townships, as shown in Tables 30a and 30b. Many of the rural areas have lost from 15 to 25% of their 1940 population in a 20-yr period, with a few in the 25-30% category. Some of the completely rural townships (those asterisked in Table 30b) have lost almost 50% of their 1910 population. What might be a reasonable lower limit for the ultimate population of these rural townships? If one introduces the concept of the 160-ac family farm, with four members per family, and uses the standard 36-section township, a population of 576 people is obtained. This appears, from the data of Table 30b, to be the situation trend today. If the family size farm increases in size to a half-section as the minimum size economic unit, and the average family size remains at four persons, then a rural township would have some 288 persons. Because farm specialization may result in more farmers living in nearby towns and limiting their operations to grain farming only, then even fewer farmsteads would result. This brief analysis does indicate that the population of these rural townships could reach a low of 250 to 300.

Maki (1965) has noted one economic effect of the decrease in rural population. The expenditures for household purchases have also decreased, but increased mechanization and specialization have caused purchases of farm production items to increase. Thus, expenditures for farm production goods and materials have increased sufficiently to more than counterbalance the decline in rural population, and the associated loss in the household sector. Maki also forecast an increase in farm size, from 173 acres in the 1960's to 231 acres by 1974. This forecast supports the population projections discussed above, with an attendant population of about 300 to 350.

The communities surrounding Ames have all experienced a greater than normal increase in population in comparison to the state and to the general region. Others are influenced by other regional trade centers such as Des Moines. These illustrate the "spin-off" benefits derived from economic and population growth at the larger center which provides increased employment opportunities for people who have a geographical preference for small towns.

Population projections for the three-county area (Boone, Hamilton, and Hardin Counties) may be made on the basis of simple graphical extension, as shown in Fig. 24. Either a stable or slightly increased rate of growth is considered sufficient for the purposes of the case study. This assumption presumes that the urban communities will have sufficient growth to offset a continued decrease of the strictly rural population on the farms. Inspection of the rural data indicates that the number of farm residents has been as high as 15 to 20 per square mile in the early decades of this century, and has decreased to a range of 10 to 15 today. The additional estimates made in this study indicated that the unit area population could decrease further to a level of 7 to 10 per square mile in the future. This minimizes the waste disposal and related stream water quality problems which might be caused by rural households, although increased per capita water use may need to be considered if specific evaluation is needed. The other agricultural waste and water quality problems, including livestock and feedlots, overshadow the rural household problem.

e. Conclusions No additional, more-sophisticated analysis is believed necessary for the population growth trends in the upper Skunk River basin outside of the Ames area. The problem of agricultural and livestock pollution and related water quality aspects surmount the human resource influence upon water quality management. It is concluded, in view of the concepts presented previously from Ackermann and Löf, that: (1) there is no predominant geographical residential preference in Iowa as evidenced by the out-migration of people; (2) the land resource, in conjunction with the hydrologic cycle and water resources availability, has responded ably to technology, thus requiring fewer human resources than in the past; and (3) the population growth at Ames can be attributed to two of the four factors of preference: (a) location of efficient service functions in the economy and (b) political or administrative considerations which have resulted in the establishment of three major employers at Ames. The latter are Iowa State University, the State Highway Commission, and the National Animal Disease Laboratory, U.S. Department of Agriculture.

E. Population Projection Models for the Ames Area

1. Past growth trend

The trend of population growth for Ames has in general been related to the growth of Iowa State University. As noted in the previous section, an almost linear growth rate was experienced by each during the period 1910-60. The university grew at the average rate of 1,630 students per decade, the remainder of the city (without students) had a growth rate of 2,670 people or residents per decade, and the combined total was 4,300 persons per decade or 430 per year. The multiplier effect (rate of increase of city without students divided by rate of increase of student enrollment) for the period 1910-60 was 1.64. This indicates that the city added 1.64 residents for each student increase in enrollment.

However, the rapid increase in both student enrollment and in urban growth since 1960 requires additional data and analysis. The detailed study methods and development of three population projection models will be reported in the following sections.

2. Selection of additional basic data and analytical techniques

The rapid rate of increase in enrollment at Iowa State University and at other colleges and universities in recent years has been attributed to the rise in birth rates in the years following World War II. Therefore, additional data were obtained concerning student enrollment and live birth statistics so that relationships between the two might be evaluated. Enrollment data at Iowa State University for the period 1954-1968 are listed in Table 31. Statistical data concerning the

Table 31. Enrollment data[a] for Iowa State University during the period 1954-1968

Year	Freshman	Sophomore	Junior	Senior	Special	Graduate	Total
1954	2,855	1,919	1,524	990	126	894	8,308
1955	3,062	2,313	1,813	918	98	972	9,176
1956	2,984	2,169	2,155	1,213	81	1,071	9,673
1957	2,874	1,999	2,210	1,544	93	1,106	9,826
1958	2,721	1,869	1,994	1,695	86	1,138	9,503
1959	2,667	1,795	1,911	1,555	119	1,205	9,252
1960	3,028	1,853	1,898	1,539	108	1,300	9,726
1961	3,165	2,172	1,960	1,531	125	1,460	10,413
1962	3,105	2,184	2,235	1,577	124	1,662	10,887
1963	3,300	2,237	2,228	1,781	166	1,805	11,517
1964	3,686	2,452	2,376	1,813	164	1,960	12,451
1965	4,370	2,763	2,676	1,890	191	2,124	14,014
1966	4,425	3,473	2,334	2,428	218	2,305	15,183
1967	4,640	3,440	3,159	2,672	197	2,733	16,841
1968	4,594	3,646	3,392	3,226	185	3,040	18,083

[a]Obtained from Office of Admissions and Records, Iowa State University.

numbers of live births in Iowa for the period 1940-67 are included in Table 32. The total enrollment at Iowa State University for the period 1960-68 is plotted in Fig. 25. Iowa State University administration projections of University enrollments are included for the period 1969-75. The live birth data for the state of Iowa are also plotted. A lag of 18 yr was selected to represent the average time interval between year of birth and the average age at enrollment of a freshman student.

Inspection of the plotted data in Fig. 25 should be made in consideration of general relationships known to exist in education. A report by the Iowa State Board of Regents (1962) indicated that two factors were relevant to the increases being experienced in college

Table 32. Population data[a] for numbers of live births in Iowa for the period 1940-1967

Year	Live births	Rate, per 1000 population	Year	Live births	Rate, per 1000 population
1940	44,347	17.5[b]	1954	63,069	23.8
1941	45,385	—[c]	1955	63,624	23.9
1942	47,671	—	1956	63,213	23.5
1943	46,579	—	1957	63,497	23.5
1944	45,263	—	1958	62,173	22.7
1945	44,497	—	1959	64,473	23.6
1946	55,743	—	1960	64,050	23.2
1947	63,536	—	1961	63,408	22.8
1948	60,396	—	1962	61,003	21.9
1949	61,765	—	1963	57,840	20.8
1950	62,550	23.8	1964	55,433	20.0
1951	66,123	25.4	1965	50,970	18.4
1952	64,091	24.5	1966	48,641	17.7
1953	62,521	23.8	1967	47,217	17.2

[a]Obtained from Iowa State Department of Health (1968).

[b]Iowa population was 2,538,000 in 1940, 2,621,000 in 1950, and 2,758,000 in 1960.

[c]Not computed, 1941-1949.

enrollment. These were the number of college age population and the percent of this number attending college or other institutions of higher learning. The implications and causal relationships illustrated in Fig. 25 can be reviewed within this framework.

First, the annual data for the peak post World War II period and for the period 1950-68 illustrate the temporal fluctuations of student enrollment about the assumed decennial growth rate. These fluctuations are due to the sensitivity of enrollment to various population, economic, social, and governmental factors including wartime effects in the 1940's,

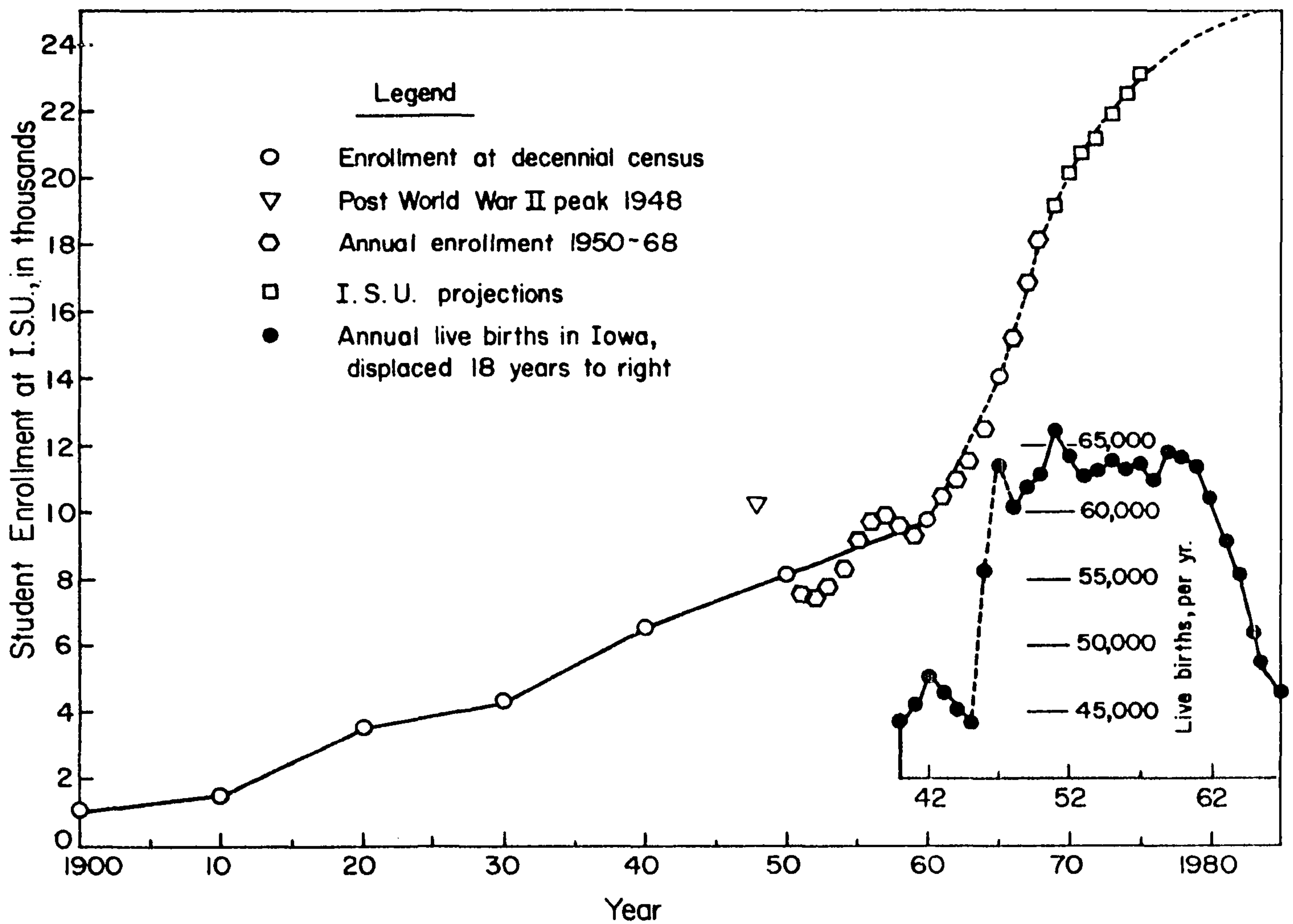

Fig. 25. Population growth trend for Iowa State University and the related effect of changes in the number of live births in Iowa.

1950's and again the late 1960's. The steady increase in enrollment since 1960 reflects the tremendous increase in live births which occurred 18 yr previously. Enrollment trends including university projections are shown in Fig. 25 through the year 1975 with extrapolation to the year 1985 based on tentative plans for an optimum size campus of 25,000 students (Johnson, Johnson, and Roy, 1968). University enrollment projections are as follows:

Year	Enrollment	Actual
1969-70	19,150	19,176
1970-71	20,100	
1971-72	20,700	
1972-73	21,300	
1973-74	21,900	
1974-75	22,500	
1975-76	23,100	

Economic and other social factors are also involved in the increased enrollments shown in Fig. 25, as increased percentages of college age population numbers attending institutions of higher learning are experienced.

A second major implication just begins to reveal itself in Fig. 25. This is the potential effect of the rapid reduction in live births which has occurred since 1961. Inspection of the data in Table 32 indicates that both the birth rate and the number of live births per year have decreased. The birth rate in 1967 was 68% of the 1951 peak value, and the number of live births was down to 71% of the peak year. These decreases, especially in the rate per 1,000 population, confirm the general trend noted in a previous discussion of trends in the United States. The data for both live births and for the birth rate, and the percent reduction values computed above, illustrate the fact that a rather stable population exists in the child-bearing age group. A review of the report of Maki (1965) and of a federal report of vital statistics (U.S. Department of Health, Education and Welfare, 1968) illustrates the dilemma faced by midwestern states in general. Out-migration of young people, especially in the 20-40 yr age group, results in a greater proportion of older people in comparison to states with increasing population rates and the national picture.

Of importance in this Iowa study is the indication in Maki's report that the age group in which child-bearing women are included will remain fairly stable to the year 1980. Because of the influence of the college age population on the growth trend of Iowa State University and Ames, forecasts of births through the period 1980 and to 2000 will permit population projections to be made for the university and the city of Ames for the year 2000 with additional but speculative projections to the year 2020. This depends, of course, on being able to develop usable relationships among these demographic variables.

3. Relating university growth to community growth

The remaining variables that must be evaluated are those relating the growth of the city of Ames (without students) to the growth experienced by Iowa State University as measured by the increases in enrollment. A ratio method using selected components of the population data was introduced to obtain meaningful relationships, based on the general concepts summarized by Isaard (1960) and McJunkin (1964) and expressed in Eq. 98a.

The data listed in Table 28 for both city and university, as modified to achieve the three categories described previously and shown in Fig. 23, were used in computing growth ratios and nonuniversity associated growth increases. The results are listed in Table 33. The increases in population per decade for each of two categories, city residents only (without students) and the student enrollment, are listed in columns 2 and 3. It is noted that the increases per decade of city residents exceeded the increase in university enrollment for all periods up to 1960. The student enrollment exceeded the former for the last 5-yr period, 1960-65. An urban growth ratio was computed by dividing the city resident increase by the student enrollment increase. Adjustments are shown for the 1960 and 1965 data for the numbers of commuting students. These commuting students are present daily and are included in the student enrollment, but are not included in actual census data as they do not reside in Ames. Thus, the actual population of the city is a temporal variable, fluctuating diurnally as students and employees move in and out of the city.

The urban growth ratio values listed in Table 33 are plotted in Fig. 26. The data show clearly that a base ratio exists between the urban growth and the enrollment increases experienced at the university. This value becomes a "basic-growth-multiplier" and a value of 1.0 was adopted for making projections for the future. Values of the urban growth ratio have varied from 0.9 (1960-65 period) to 5.45 (1920-30 period). Only during two decades, 1900-10 and 1920-30, has the ratio

Table 33. Growth ratio data computed from census data, Ames and Iowa State University

Census year	Population increase, per decade: City residents only	Population increase, per decade: Student enrollment	Growth ratio city/I.S.U.[a]	Estimated growth not associated with I.S.U., percent annual increase[b]
1900				
	1,801	485	3.72	5.44
1910				
	2,047	2,037	1.01	0.02
1920				
	3,991	734	5.45	5.20
1930				
	2,294	2,249	1.02	0.04
1940				
	2,208	1,568	1.41	0.51
1950				
	2,514 (2,805)[c]	1,591	1.58 (1.76)[c]	0.82
1960				
1965	3,544 (3,838)[c]	4,288	0.83 (0.90)[c]	—
			Avg.	2.0%

[a]Computed by dividing per decade city increase by enrollment increase.

[b]Assumes base level growth ratio of 1.0, with remaining city residential per decade increase expressed as percentage of beginning-of-decade city residential population (without students).

[c]Modified value for city residents to account for commuting students, 1960 and 1965.

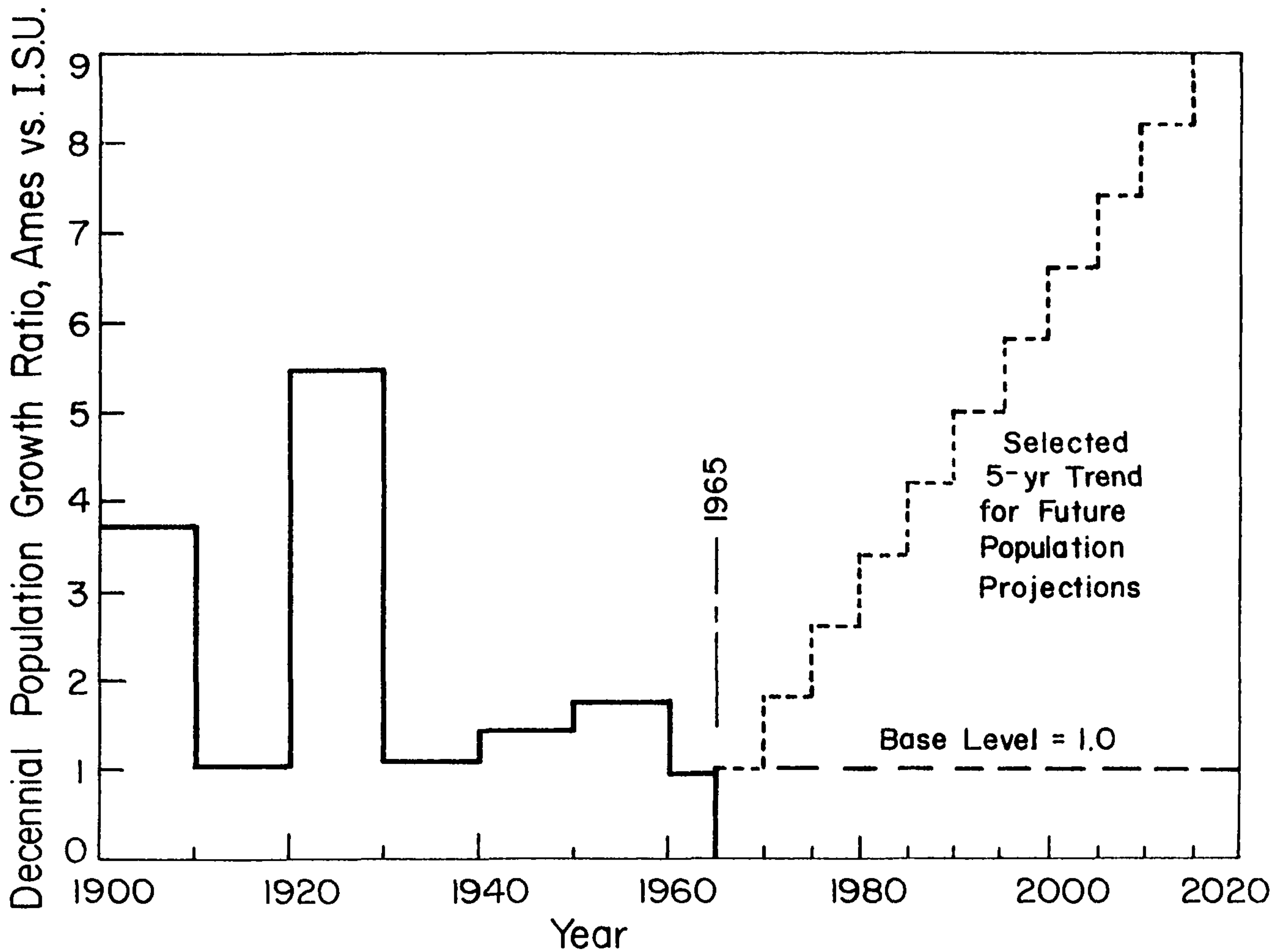

Fig. 26. Computed decennial urban growth ratios for city versus university population increases.

gone above a value of 1.8. The economic reasons for these "independent" spurts was not investigated, but might be the subject of additional research. It was assumed that additional economic activity not directly related to the university was responsible for the slowly increasing values of the ratio during the period 1940-60, to a value of 1.6 to 1.8 in 1960.

The decrease in the urban growth ratio since 1960 parallels the rapid increase in enrollment. In fact, the experienced ratio of 0.8 to 0.9 is below the adopted basic-growth-multiplier value of 1.0. Additional inspection of the annual reports of Iowa State University (1968) indicated that the student to faculty ratio was 9.0:1 in 1960, 9.9:1 in 1965, and had increased to 10.4:1 in 1968. This represents a faculty employment multiplier of about 0.1 today based on student enrollment figures. Adding to the faculty numbers the clerical, employed graduate teaching and research students, and other administrative staff results in student to staff ratios of 3.8:1 in 1960, 4.21:1 in 1965, and 4.9:1 in 1968, for an overall employment-multiplier value of about 0.2. There is some double counting across the data, since the employed graduate students are also counted as students. The results do show that the university has become more efficient in meeting the increased enrollment, and in view of the increased research emphasis, the teaching role has been accomplished with less increase in faculty than indicated by previous years' experience.

The results also indicate that the university employment multiplier of 0.2 swells to an urban growth ratio of 1.0, based on increases in student enrollment, an increase of five times. This increase includes staff and faculty families and related growth of business and commerce to accommodate the increased student enrollment and university employment. Increases in the urban growth ratio above the basic-growth-multiplier value of 1 must originate in other sectors of the local economy. Growth of the Highway Commission headquarters staff, the National Animal Disease Laboratory, and other private industry and commerce are involved in this role, but to date they have not overshadowed the university's influence on the growth of Ames. To represent two separate alternatives in estimating future urban growth, a static model and a dynamic model of growth will be used. The base level of 1.0 is the minimum urban ratio to be used. To represent the optimum or maximum urban growth potential, the step increases shown in Fig. 26 are adopted, based on achieving a level of 5.0 by 1990. An intermediate level might be more realistic, but the indicated values provide the range considered reasonably probable of occurrence in the future. The probability of a major employer selecting Ames as the site of a new facility must not be discounted, and could easily upset the experienced pattern. However, this was assumed away in the detailed analysis of future population, water supply, and water quality control requirements for the purposes of the case study being made herein.

Because of the inherent inaccuracies which may accompany the selection of an urban growth ratio of more than one, which limits urban growth increases in the future to the university growth completely, a second method was introduced. This was made to provide an urban growth increase, above the basic-growth-multiplier value of 1.0, which would be independent of the university growth. A nonuniversity related growth increase percentage was determined from the basic data included in Table 38, for the period 1900-60. This percentage was computed by first subtracting from each decade increase of city residents in column 2 the base level growth caused by the ratio of 1.0. For example, the estimated nonuniversity related growth percentage for the decade 1900-10 was computed by subtracting the student enrollment increase from the total city residents increase (1,801 - 485 = 1,316), then expressing this increase as a percent of the beginning-of-decade residential population (without students) as shown in Fig. 23 (1,316/2,422 = 54.4% for the decade, or a simple 5.4% annually over the 10-yr period). The average for the period 1900-60 was 20% per decade (or 2.0% annually for 10-yr periods, 10% for the 5-yr periods used subsequently in making projections). These results are listed in column 5 of Table 33. Use of this technique provides an alternative in estimating future increases in the urban residents of Ames. For a given increase in student enrollment, the urban growth (residential population without students) equals the increase in student enrollment plus a 2% annual increase due to additional economic activity of nonuniversity related business and commerce and other industrial growth, based on beginning-of-period city residential population.

4. Relating student enrollment characteristics to the college age population

a. Basic considerations Additional analysis of student enrollment data was made to evaluate the growth trends for Iowa State University. A relative measure of both the college age population and the college age freshman population was desired to serve as the basis of the evaluation.

A means of modifying the live birth data was studied in this phase from which the basis was formed. This permitted the university enrollment characteristics to be related to the simulated college age population groups.

Analysis of statistical data of the U.S. Department of Health, Education and Welfare (1967, 1968) indicated that a 3% mortality factor could be assigned to the live birth numbers to represent the reduction in members of young people from birth to age 18. Review of data collated by Maki (1965) and of federal vital statistics (U.S. Department of Health, Education and Welfare, 1967, 1968) showed that some out-migration in the 0- to 18-yr age group could be expected but would be minor compared to that occurring after the 24-yr old level is reached. A migration loss of 3% was adopted for the purposes of the case study at Ames. The combined effect of mortality and out-migration is roughly 6%. This means that the number of live births in a specific year, reduced by 6%, becomes the freshman age population 18 yr later. Or conversely, the survival rate is 94%. This simulated group is an approximation and serves as an indicator of the true freshman age group which will have some 17-yr olds, a greater number of 18-yr olds, and a sprinkling of the other but older age groups. The single age group was used in this analysis to simplify the computations, but additional refinements in the technique could be made by determining the appropriate percent of 17-, 18-, 19-, etc. yr old youth to place in the freshman age group. In this study, the college age population (for all undergraduates) was selected as the age group of 18 through 21 yr. This is associated with the live births occurring 18 to 21 yr previously, as reduced for mortality and migration.

b. Two methods of relating I.S.U. enrollment to simulated college age group The first method selected was simply to correlate the total student enrollment with the simulated college age population. This lumps the special and graduate student enrollment with the undergraduate enrollment and presumes that the simulated college age population group can act as an indicator group for making future projections. Inspection of the data in Table 31 shows that the graduate college has increased at a rapid rate, greater than the rate of increase for the total undergraduates but comparable to the rate of increase experienced by the senior class. Therefore, it does not appear unreasonable to use the lumped total enrollment as a variable in this initial method. The college age population was obtained by summing the live births for four consecutive years, correcting for 94% survival (mortality and out-migration), and lagging the total 18 yr to represent the total college age group at that time. For the year 1968, for example, the live births in 1947, 1948, 1949, and 1950 were totaled; seniors in 1968 came from the 1947 live birth group, etc. The results of this analysis for the growth period 1958-1968 are plotted in Fig. 27. The regression equation obtained from this analysis was

$$Y = 5.75 + 0.25 (X - 1960) \quad (99)$$

where

Y - percent of college age population group attending Iowa State University in a specified year, and

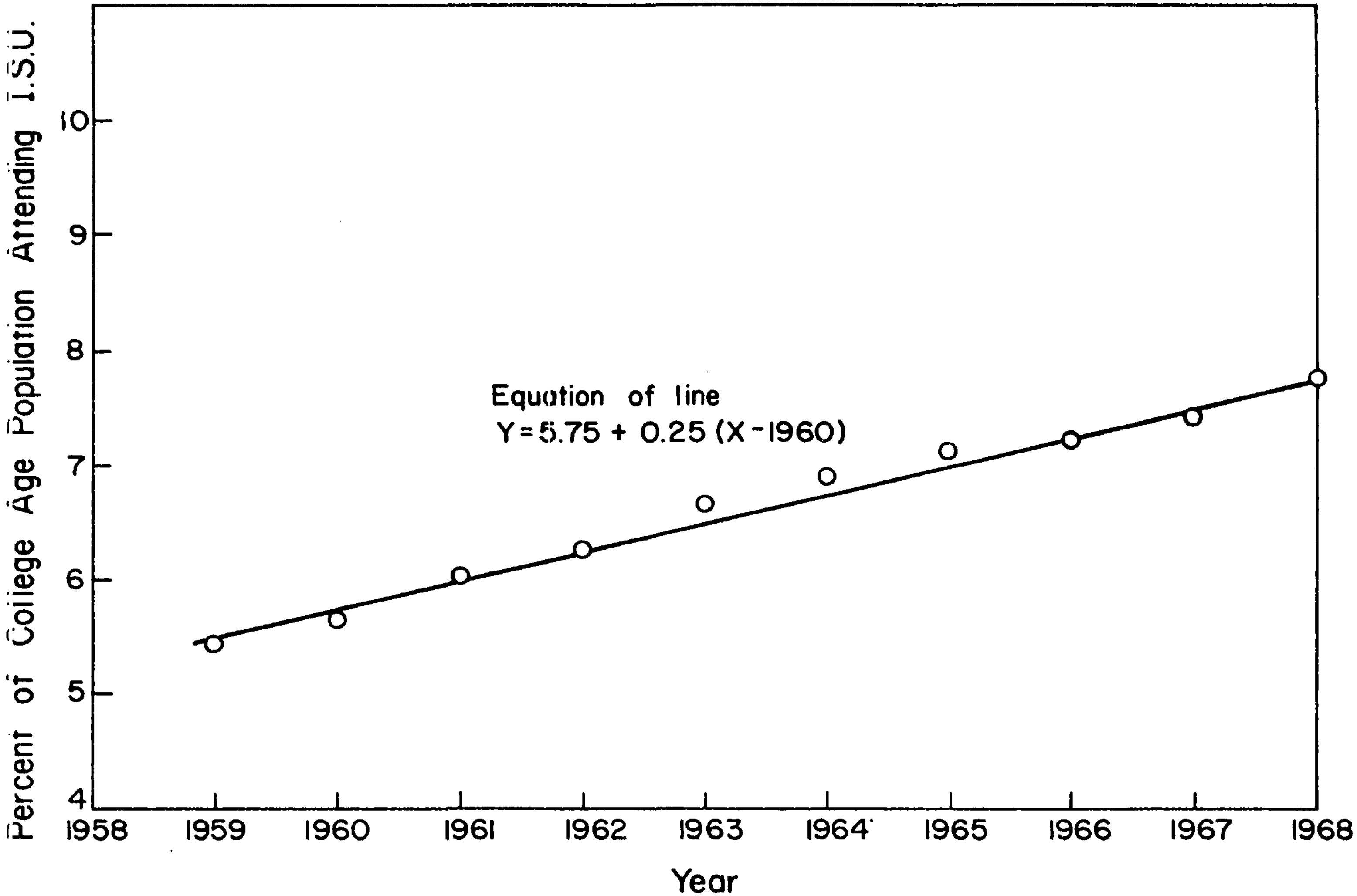

Fig. 27. Annual relationships of enrollment at Iowa State University as percent of simulated Iowa college age population.

X = year since 1958 for which a value of Y may be computed. The correlation coefficient for the regression was 0.992 with a standard error of estimate of 0.102. The equation applies for the period 1958-1968 and the base 1960 was used as a reference to facilitate computations for future projections. The relationship shown in Fig. 27 indicates that this initial method provides a satisfactory technique for making projections for a limited period in the future, realizing from analysis of the past experience that many additional factors may enter into the college enrollment picture.

The care which must be exercised in using this temporal relationship can be illustrated using information contained in a report of the Iowa State Board of Regents (1962). Obviously, if Eq. 99 was extended for many years, practically all of the youth attending college would attend Iowa State University. The regent's report indicated that about 45 to 50% of the college enrollment at Iowa colleges and universities, both public and private, occurred at the three state institutions of higher learning. These schools are Iowa State University, the University of Iowa, and the University of Northern Iowa. The percent attending state schools has varied being 50% or more in the period 1953-55, decreasing to 45% in 1961, but increasing in the late 1960's to values above 50%. However, an average of 40% of the state school portion of the total have attended Iowa State University throughout this period.

If it is assumed that one-third of the college age population group in 1962 were continuing their education at institutions of higher learning, then estimates of the percent attending Iowa State University can be checked. It is assumed in this analysis, as implied in developing Eq. 99, that the inflow of out-of-state students equals the outflow of Iowa college age students to out-of-state schools, so that the Iowa college age population will serve as an adequate basis for estimating. This probably is not precisely true, in view of the population stress in eastern states and the numbers of out-of-state students attending such private colleges in Iowa as Parsons College at Fairfield, etc. However, the differences will be assumed away for the purposes of this analysis, which is directed primarily towards estimating water supply and water quality control requirements. Accepting these limitations, the overall percent of college age population attending Iowa State University in 1961-1962 would be 0.40 x 0.45 x 1/3 or 0.06 x 100 = 6.0%. The actual percentage in 1962 was 6.26%, climbing to 7.75% in 1968.

A rough estimate of the maximum percent of Iowa college age population who might attend Iowa State University in the future can now be made, using the technique just illustrated. For this ultimate percentage, it will be assumed that the maximum number of college age population attending institutions of higher learning will approach a ratio of one-half, and that about 60% will attend the state schools. If Iowa State University continues to retain its 40% share, then an ultimate percentage of 0.40 x 0.60 x 1/2 x 100 or 12% is obtained. These maximum values must be tempered in view of the increasing role of the area vocational-technical schools and the proposal to establish a fourth school of higher education in western Iowa. Again, it is assumed that the special students and the graduate students can be lumped into these estimates. For the purposes of this study, a maximum value of 12% will be used to represent the upper limit of the university's growth trend for this first projection model.

The second method which will be used to make projections of the future size of Iowa State University will be based on the component method (Isaard, 1960). This method involves estimating the relationship between the numbers of freshman enrolled at Iowa State University and the simulated college age freshman age group (94% of the live births 18 yr previous to the date desired). Then, the percent "survival" or advancement percentages are determined for subsequent 2nd, 3rd, and 4th years of school. The graduate enrollment is expressed as a percent of the undergraduate enrollment, with special students lumped with the graduates. Summation of the proper components each year then provides the total school enrollment.

The data computed for this second method, and the data for the first method also, are listed in Table 34. Data included in Table 31 provided the basis for the computations. The relationship between the freshman enrollment at Iowa State University and the simulated freshman age population group is illustrated in Fig. 28. As might be expected in using smaller and smaller components, additional variations are observed in the plotted data. Five-yr moving means were computed and plotted, and used in fitting a regression line to the data. The adopted regression line is expressed by

$$Y = 6.96 + 0.13 (X - 1960) \tag{100}$$

where

Table 34. Computed percentages of Iowa State University enrollment components for various categories[a]

Year	Total student enrollment	Simulated college age population	Percent I.S.U. of total	Freshman enrollment	Percent of simulated freshman group	Advancement percentages, as percent of beginning freshman			Graduate and specials, percent of undergraduate
						Sophomores	Juniors	Seniors	
1954	8,308	—	—	2,855	—	81.02	75.48	54.08	14.0
1955	9,176	—	—	3,062	—	70.84	72.18	55.36	13.2
1956	9,673	—	—	2,984	—	66.99	66.82	52.11	13.5
1957	9,826	—	—	2,874	—	65.03	66.49	53.55	13.9
1958	9,503	172,000	5.52	2,721	6.53	65.97	69.75	56.27	14.8
1959	9,252	171,000	5.42	2,667	6.24	69.48	73.49	59.13	16.7
1960	9,726	172,000	5.65	3,028	6.76	71.73	73.81	58.82	16.9
1961	10,413	173,000	6.02	3,165	7.23	69.00	70.39	57.28	17.9
1962	10,887	174,000	6.26	3,105	7.30	72.05	76.52	60.87	19.6
1963	11,517	173,000	6.66	3,300	7.89	74.30	81.09	73.58	20.6
1964	12,451	181,000	6.90	3,686	7.03	74.96	63.32	72.49	20.6
1965	14,014	196,000	7.13	4,370	7.32	79.47	72.29	73.82	19.8
1966	15,183	211,000	7.21	4,425	7.79	77.74	76.66	—	19.9
1967	16,841	227,000	7.42	4,640	7.99	78.58	—	—	21.1
1968	18,083	233,000	7.75	4,594	7.81	—	—	—	21.7

[a]Basic data obtained from Tables 31 and 32.

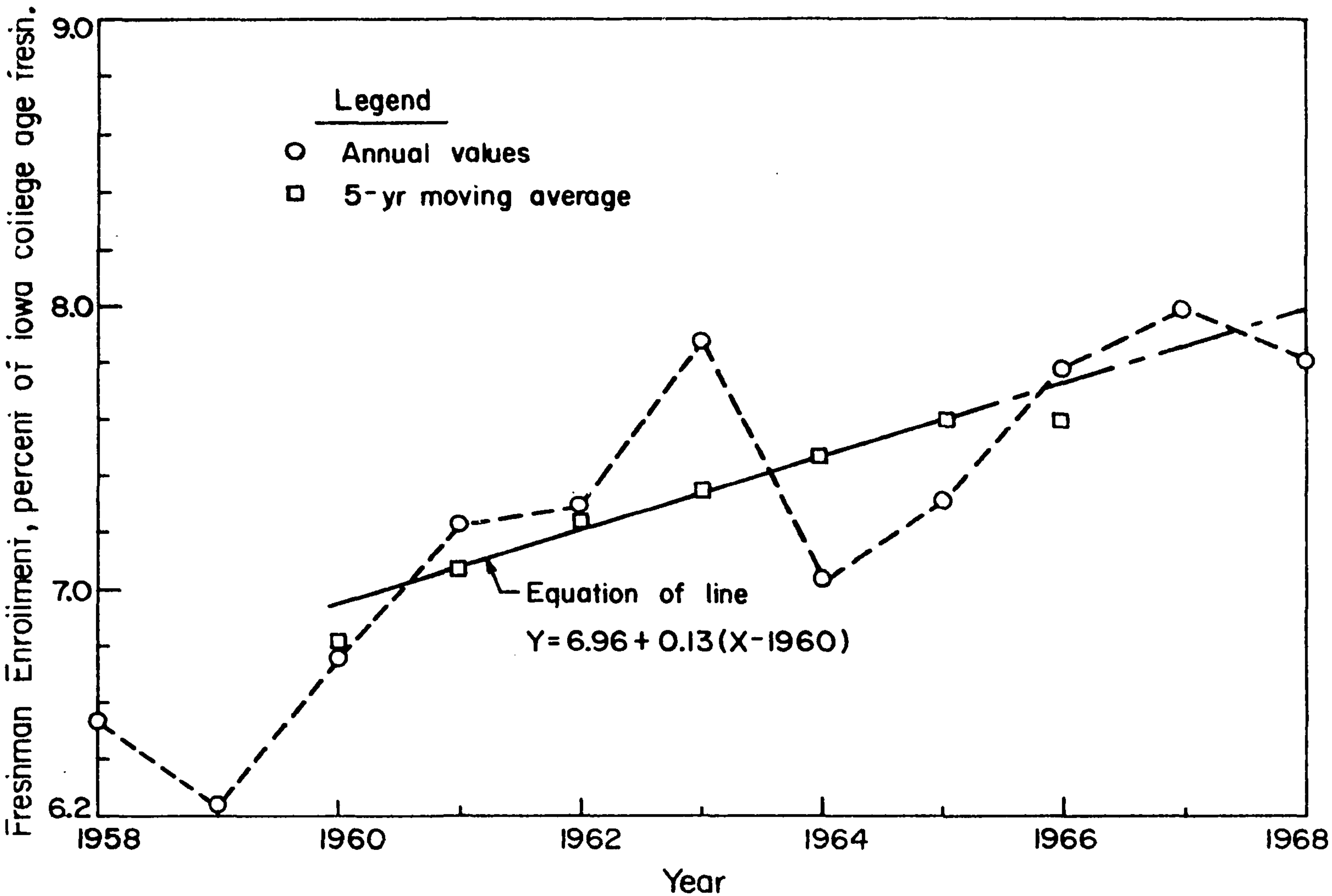

Fig. 28. Growth trend of freshman enrollment at Iowa State University as percent of simulated Iowa college age freshman group.

Y = percent of Iowa college age freshman group attending Iowa State University, and

X = year for which Y is to be computed, beginning in 1958.

The correlation coefficient for the 1959-67 period used in curve fitting was 0.998 with a standard error of estimate of 0.146.

The relationship of graduate and special student enrollment, as a percent of total undergraduate enrollment, is shown in Fig. 29. A definite trend exists, and the 5-yr moving means smooth out the annual values. However, the trend is not linear, but S-shaped similar to a Gompertz curve or a logistic curve (Isaard, 1960, pp. 13-14). The decreasing trend of recent years may be due to several factors, including the draft situation, economics of graduate education and influence of high salary offers from employers, or simply the fact that only a certain percentage of graduating seniors will be of graduate caliber. Both a constant percentage and a straight line increase were used in subsequent development of projection models.

The successive year survival percentages, or advancement percentages, of the sophomore, junior and senior classes as shown in Table 34 were not plotted. Instead, averages were computed and general estimates made of the increasing trends indicated in Table 34. The average long-term value for sophomores was 73% of the incoming freshmen (of the prior year's freshmen); the average over the last 5 yr was 77%, and the percentage is now approaching 80%. The percent of this beginning freshman class reaching the junior level was 72% for the entire study period, 74% for the last 5 yr, and is approaching 76 to 77%. Undoubtedly some transfer students from 2-yr programs in other schools in the state are

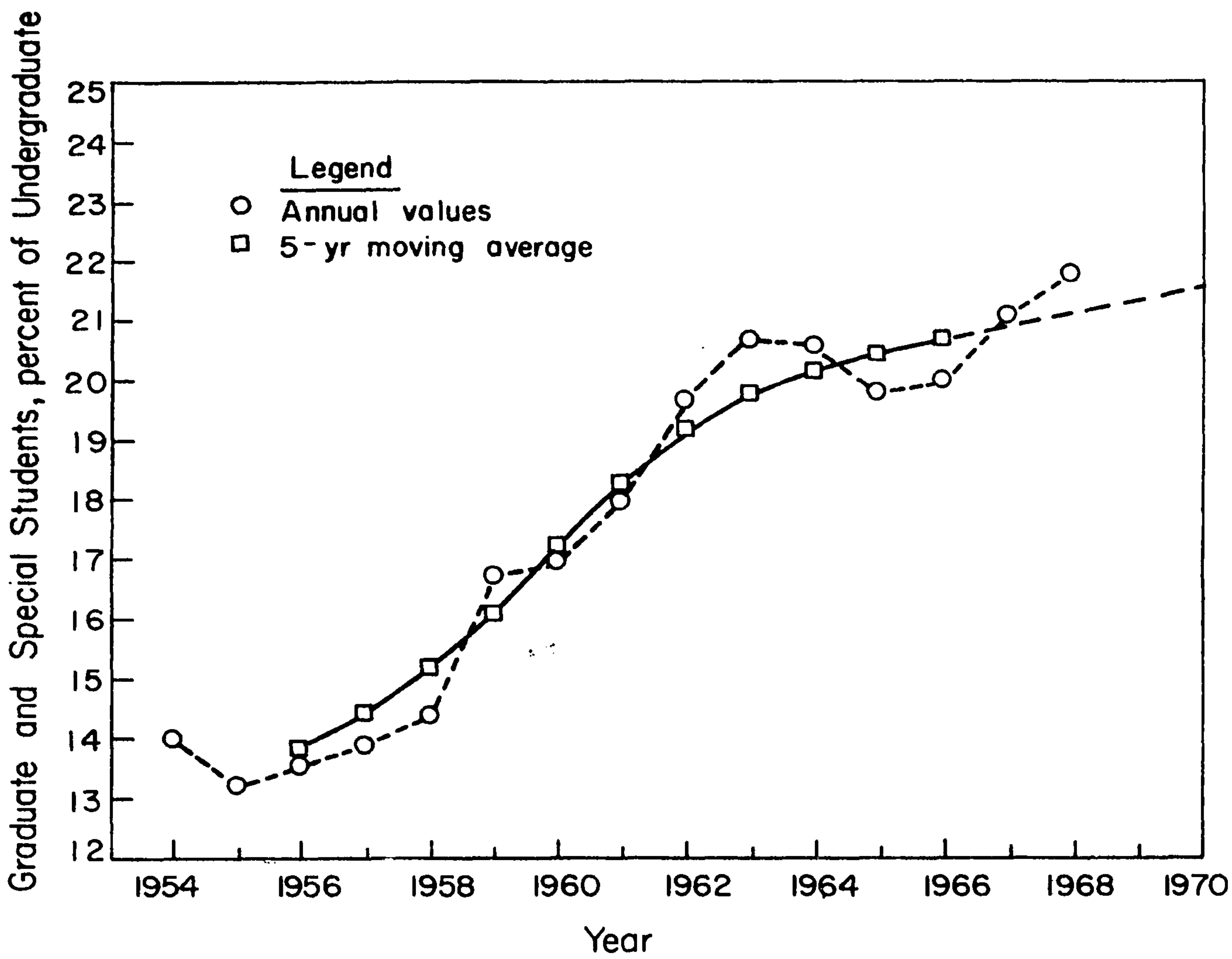

Fig. 29. Growth trend of graduate and special students as percent of undergraduate enrollment.

included indirectly in this tabulation. A very definite trend is evident in the percentages of incoming freshman who reach the senior or 4th year level. The average for the study period is 61%, 68% for the last 5 yr, and appears to be approaching the 74 to 75% level today. In the models developed and used subsequently, constant averages were adopted for a static version, and linear increases to upper limits were used in a dynamic model.

c. Summary of interrelationships and interactions In applying the quantitative relationships which have been developed between student enrollment and the simulated college age population, and between the university total enrollment increases and increases in the city residents, several additional influences must be considered. These interrelationships and interactions are described below.

1. Policy and decision making of the Iowa General Assembly and of the Board of Regents which concern:

    a. Desired optimum size of the Iowa State University and the other state institutions of higher learning; the desired optimum size for I.S.U. is now in the range of 25,000 students, because of space limitations, land use patterns, need for buildings and other facilities, etc.

    b. Potential for a fourth state institution of higher learning, with the initial planning study and location in western Iowa determined, as requested by the General Assembly.

    c. Impact of the new area community colleges in Iowa, as created by the General Assembly for increased emphasis on vocational and technical training but including pre-professional college coursework.

2. Educational mix in the future as among undergraduate, transfer, graduate and special students, and in the field of extension, continuing education and off-campus coursework including the use of educational television network and closed circuit television.

3. Potential effect of the declining birth rate in Iowa (and other states contributing to non-resident student population), and of migration patterns.

4. Additional business, commercial and industrial growth that might be encouraged to locate in Ames because of the university environment.

Based upon the simulated college age population group and applying the relationships among the population components and between university growth and city growth that have been derived, projection models were developed for estimating the potential growth of the Ames area. Four projection models were used in the study, and were labeled Model I, II, III, and IV. In addition, two methods were used in three of the models for estimating the increases in city residents, method (1) using the urban growth ratios illustrated in Fig. 26, and method (2) using the basic growth multiplier of 1.0 with an added 10% growth per 5-yr period based on the beginning-of-period, city-residents-only population. Selection of the appropriate model, and associated projection values, for final application to the water supply and water quality forecasting problem depends on subjective analysis of the four interactions listed above.

5. Population Projection Model I

a. Development of the population model   The assumptions which are included in the development of Population Projection Model I are summarized as:

a. State population projections of the U.S. Senate (1960b), Series IV-1, as modified in Table 27 for this case study, will apply.

b. For a specific year, N, in the period 1970-2020, the college age population, CAP, is estimated from actual or projected live births, LB, as

$$CAP(N) = 0.94 \sum_{I=21}^{I=18} LB(N - I) \qquad (101a)$$

c. The birth rate for the period 1970-2020 would remain at the present level, 17 per 1,000, and the state population would increase from 2.8 million in 1970 to 3.0 million in 1980 and to 3.5 million in 2000. This is expressed mathematically as

$$\begin{cases} LB(N) = \text{recorded } LB(N) & N \leq 1967 \\ LB(N) = 0.017\,[2{,}800{,}000 + 20{,}000 \times (N - 1970)] & 1968 \leq N \leq 1980 \\ LB(N) = 0.017\,[3{,}000{,}000 + 25{,}000 \times (N - 1980)] & 1980 < N \leq 2020 \end{cases} \qquad (101b)$$

d. The percent of the simulated college age population attending Iowa State University during the period 1968-2020 is estimated using Eq. 99 with an upper limit of 12.0%, or

$$\begin{cases} Y(N) = 5.75 + 0.25 \times (N - 1960) & N < 1985 \\ Y(N) = 12.0 & N \geq 1985 \end{cases} \qquad (101c)$$

e. The student enrollment is computed as the product of Eqs. 101a and 101c, for the total student enrollment at Iowa State University, SE,

$$SE(N) = \frac{1}{100} \times Y(N) \times CAP(N) \qquad (101d)$$

f. For method A, estimates of the city residents are made using the urban growth ratios shown in Fig. 26 as step increases of 0.16 for each 5-yr planning period. During decades when no growth or a decline in university enrollment occurs, a minimum 2% annual increase (10% every 5 yr) in city residents will be used. In the mathematical model this becomes, for the urban growth rate CGR and its associated incremental growth of city residential population, ΔCRP, for 5-yr increments

$$CGR\Big|_{N-5}^{N} = 1.0 + 0.16 \times (N - 1970) \qquad 1970 \leq N \leq 2020$$

$$\begin{cases} \Delta CRP\Big|_{N-5}^{N} = CGR\Big|_{N-5}^{N} \times [SE(N) - SE(N - 5)] & [SE(N) - SE(N - 5)] > 0 \\ \Delta CRP\Big|_{N-5}^{N} = 0.10 \times CRP(N - 5) & [SE(N) - SE(N - 5)] < 0 \end{cases}$$

(101e)

g. For method B, estimates of the city residents are made using the basic growth multiplier of 1.0 based on the student enrollment increase, with an additional 10% growth every 5 yr based on the city residential population at the beginning of the period. In the mathematical model, this requires first estimating the base level of city growth, BLCG, using the basic growth multiplier, and second, computing the additional city growth, ADCG, based on outside economic growth as expressed as an increase from the beginning-of-period residents only population, or

$$BLCG \Big|_{N-5}^{N} = 1.0[SE(N) - SE(N-5)] \qquad 1970 \leq N \leq 2020 \text{ and } BLCG \geq 0 \qquad (101f)$$

$$= 0.0 \qquad \text{otherwise}$$

$$ADCG \Big|_{N-5}^{N} = 0.10 \times CRP(N-5) \qquad 1975 \leq N \leq 2025$$

$$\Delta CRP \Big|_{N-5}^{N} = BLCG \Big|_{N-5}^{N} + ADCG \Big|_{N-5}^{N}$$

h. The total population of Ames, student enrollment and city residents categories combined, is then obtained in two steps. First the total city residents only category, CRP, is obtained for a specific year, with 5-yr steps being used, and then the student enrollment is added, SE, and the total population of Ames, TPA, is given:

$$CRP(N) = CRP(N-5) + \Delta CRP \Big|_{N-5}^{N} \qquad 1970 \leq N \leq 2020 \qquad (101g)$$

$$TPA(N) = CRP(N) + SE(N) \qquad 1970 \leq N \leq 2020$$

b. Results and discussion The results obtained using Population Projection Model I are included in Table 35 and shown in Fig. 30. The projections reveal the potential effect of the decreasing birth rate in Iowa on the future population of the university community. The

Table 35. Population projections for Ames for period 1970-2020, as determined with Population Projection Model I, relating total student enrollment to estimated college age population[a]

Year	Simulated college age population	Percent attending I.S.U.	Total student enrollment	Total population of Ames: Method A, City residents	Method A, Total	Method B, City residents	Method B, Total
1960[b]	170,000	5.75	9,780[b]	–	–	–	–
1965[b]	196,500	7.00	13,760[b]	21,400	35,160	21,400	35,160
1970	239,260	8.25	19,740	26,560	46,300	26,560	46,300
1975	238,200	9.50	22,630	31,760	54,390	32,100	54,730
1980	237,760	10.75	25,560	39,380	64,940	38,240	63,800
1985	190,140	12.0	22,820	43,320	66,140	42,070	64,890
1990	179,880	12.0	21,580	47,650	69,230	46,280	67,860
1995	186,010	12.0	22,320	51,330	73,650	51,640	73,960
2000	192,640	12.0	23,120	55,940	79,060	57,600	80,720
2005	200,550	12.0	24,070	62,210	86,280	64,310	88,380
2010	208,540	12.0	25,030	69,300	94,330	71,700	96,730
2015	216,530	12.0	25,980	77,160	103,140	79,830	105,810
2020	224,520	12.0	26,940	85,790	112,730	88,770	115,710

[a]Computations based on live birth data for Iowa, modified state population projections, and derived relationships for enrollment percentages and city-university growth ratios; see text for criteria and application concepts.

[b]Comparative data; actual enrollment was 9,726 in 1960 and 14,014 in 1965.

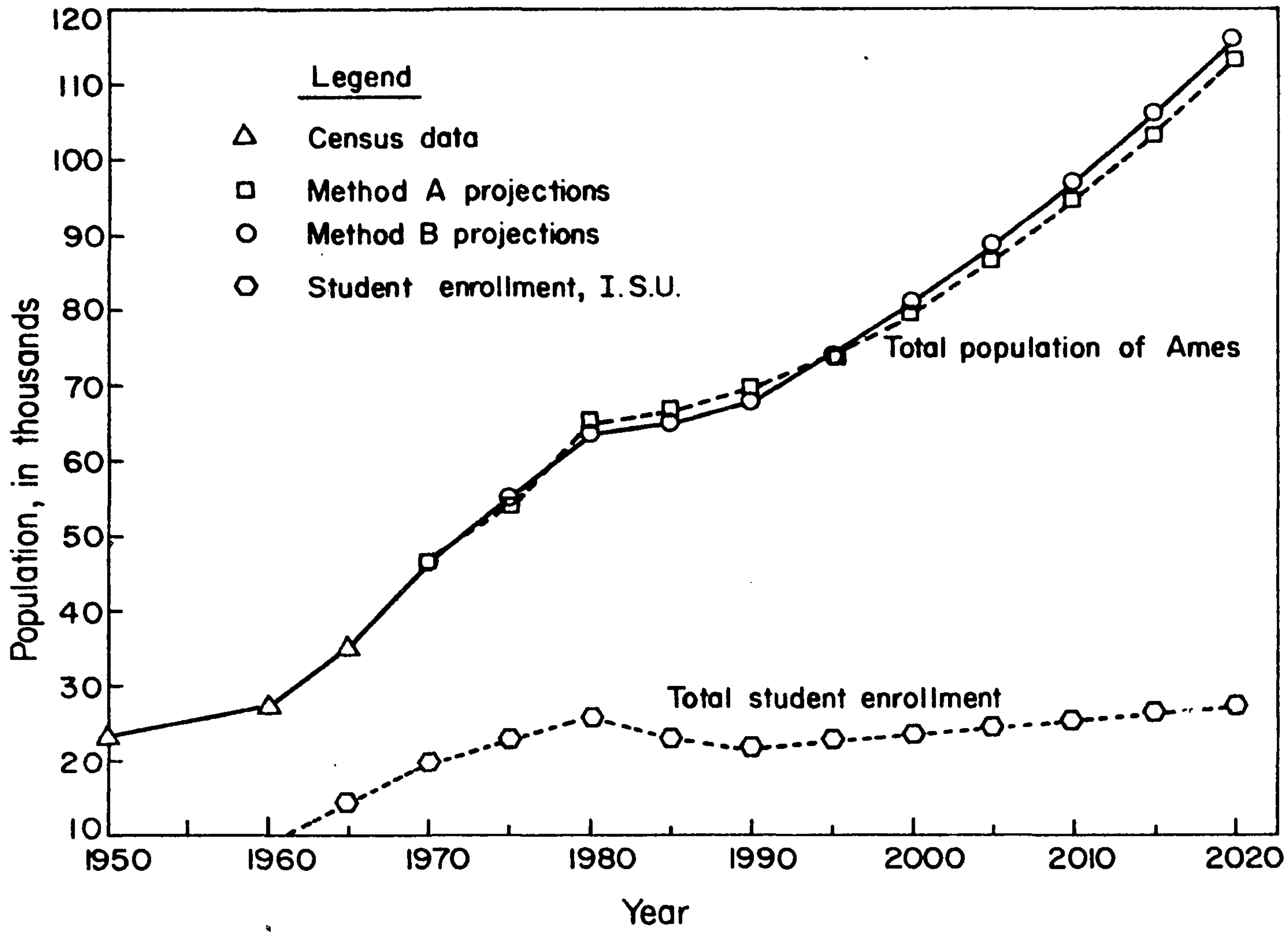

Fig. 30. Population projections for the city of Ames and Iowa State University using Model I, Methods A and B, for the period 1970-2020.

model does verify the forecasts made by the university administration and supports the optimum size of 25,000 students.

One important factor became evident in developing and applying the model. The assumptions made which related student enrollment and the college age population group to the numbers of live births imply that the live birth rate in 1967 (the last year for which data were collected) establishes the freshman age group for the year 1985. This means that population projections through 1985 have the greatest probability of being correct, and are not influenced by estimates of the state population made prior to that year. Thus, the "die is cast" insofar as the growth potential of the university and the city are concerned, except for the influence of out-of-state students on the university and additional commercial and industrial growth for the city.

The reduction in live births and in the simulated freshman age group 18 yr later causes a decrease in the student enrollment in the period 1980-90. Also, the increase in student enrollment after 1990 is based on a slightly increased rate of growth of the state population, more than has recently been experienced. This growth trend of the state population and the numbers of live births should be observed carefully in the future if continued predictions are to be made to update the results obtained in this initial study.

The results obtained with Model I are considered to be optimum in terms of the potential for university and city growth. If additional factors arise that prevent the percent of students enrolling at Iowa State University from reaching the estimated 12% maximum, then a greater reduction in student enrollment following the year 1980 would result. Also, unless the business and industrial environment continues to thrive and support the 2% annual growth (simple interest concept per 5- or 10-yr period, not compounded), based on the city-residents-without-students population base, then the plateau observed following the year 1980 would be much sharper. A brief analysis was made neglecting the 2% growth factor, and an actual loss in urban population resulted. The results shown in Fig. 30 indicate that little difference occurred between methods A and B. Both provided about the same projections for future conditions.

6. Population Projection Model II (static)

a. Elements of the population model   Because so many variables appeared to be lumped into the first model where it was assumed that the total student enrollment could be correlated with the simulated college age population, additional refinement was introduced into Model II. These refinements included several factors. First, separate emphasis on special and graduate student enrollment was desired. Second, additional insight was obtained by separating the college age undergraduate group into four classes, freshman through senior (neglecting 5th year categories or the fact that many students graduate after 4-1/2 to 5 yr in a 4-yr curriculum). Once freshman enrollment projections were made, advancement percentages based on the data of Table 34 were used, and special and graduate enrollment computed and added to the total undergraduate.

Population Projection Model II is introduced to reflect static conditions. Based on a review of the data as contained in Table 34, it was determined that the percentages to be applied throughout the planning period would be those values being approached at the end of the 1960's:

Group	Percentage	Description
Iowa freshman age group	94	Actual or estimated live births 18 yr prior to desired year.
I.S.U. freshman enrollment	8	Of Iowa freshman age group.
I.S.U. sophomore enrollment	80	Advancement percentage from freshman class to sophomore class.
I.S.U. junior enrollment	77	Advancement percentage applied to the freshman enrollment 2 yr previous.
I.S.U. senior enrollment	74	Advancement percentage applied to the freshman enrollment 3 yr previous.
I.S.U. special and graduate student enrollment	22	Percent of total undergraduate enrollment.

These values, obtained from inspection of Figs. 28, 29, and Table 34, are based on the concept that limiting values are being reached as of the end of the 1960's and no real increase can be expected because of the interactions listed previously. The mathematical model constructed to represent Model II included the following segments.

a. Freshman enrollment, FREN, is given for any year N, by

$$FREN(N) = 0.08 \times 0.94 \times LB(N - 18) \qquad 1968 \leq N \leq 2020 \qquad (102a)$$

b. Sophomore enrollment, SOEN, for any year N is computed as

$$SOEN(N) = 0.80 \times FREN(N - 1) \qquad 1967 \leq N \leq 2020 \qquad (102b)$$

c. The junior enrollment, JREN, for any year N is computed as

$$JREN(N) = 0.77 \times FREN(N - 2) \qquad 1966 \leq N \leq 2020 \quad (102c)$$

d. The senior enrollment, SREN, for any year N is computed as

$$SREN(N) = 0.74 \times FREN(N - 3) \qquad 1965 \leq N \leq 2020 \quad (102d)$$

e. The total undergraduate enrollment, UGEN, is the sum of the four,

$$UGEN(N) = FREN(N) + SOEN(N) + JREN(N) + SREN(N) \quad (102e)$$

f. The graduate and special student enrollment is then computed as

$$GSEN(N) = 0.22 \times UGEN(N) \quad (102f)$$

g. The total student enrollment, SE(N), is given by

$$SE(N) = UGEN(N) + GSEN(N) = 1.22 \times UGEN(N) \quad (102g)$$

h. The city residents category is computed as previously given in Eqs. 101e, 101f, and 101g, for the total residents and students. The state population would be in accordance with that projected with Model I, using the modified Series IV-1 of the U.S. Bureau of Census. The birth rate for Iowa remains at 17 per 1,000 population as with Model I estimates.

b. Results and discussion The results obtained with Population Projection Model II for static conditions of enrollment at Iowa State University are listed in Table 36, for both Methods A and B. The projections are plotted in Figs. 31 and 32, along with the results for Models III and IV (to be developed next). The results obtained using Model II reflect the importance of the live birth rate and numbers of live births on university attendance. According to these results, the total student enrollment reaches a plateau during the period 1970-80 at a level between 19,000 and 20,000, then sags to a low before recovering in the 1990's. Similarly, the total city population shows a definite plateau at the year 1980. Further, the decline in student enrollment

Table 36. Population projections for Ames for period 1970-2020 as determined with Population Projection Model II, relating incoming freshman to estimated Iowa freshman age group as a constant-percentage (static model)[a]

Year	Simulated freshman age group	Total student enrollment	Total population: Method A City residents	Method A Total	Method B City residents	Method B Total
1965	59,720	14,010[b]	21,400	35,410	21,400	35,410
1970	60,250	19,170	26,570	45,740	26,570	45,740
1975	59,690	19,240	29,220	48,460	29,290	48,530
1980	57,340	19,150	32,150	51,300	32,220	51,370
1985	44,380	15,270	35,360	50,630	35,440	50,710
1990	45,380	14,540	38,900	53,440	38,990	53,530
1995	46,980	15,030	41,370	56,400	43,380	58,410
2000	48,740	15,570	44,490	60,060	48,250	63,830
2005	50,740	16,210	48,720	64,930	53,720	69,930
2010	52,730	16,860	53,500	70,360	59,740	76,600
2015	54,730	17,510	58,800	76,310	66,350	83,860
2020	56,730	18,150	64,580	82,730	73,640	91,790

[a]Compuations based on live births for Iowa, modified state population projections, and derived relationships for enrollment percentages and city-university growth ratios; see text for criteria and application concepts.

[b]Actual, not projected enrollment, with 4,372 freshman (7.32%).

more than offsets the 10% growth in city residents permitted by the model, so that a loss in total city population occurs in the period 1980-85, for both methods A and B. Again, the projected increase in state population from the modified Series IV-1 projections permits some increase to be noted after 1990.

As with Model I results, those obtained with Model II illustrate the sensitivity of the total city population and its growth to the university growth pattern. The latter pattern cannot be expected to

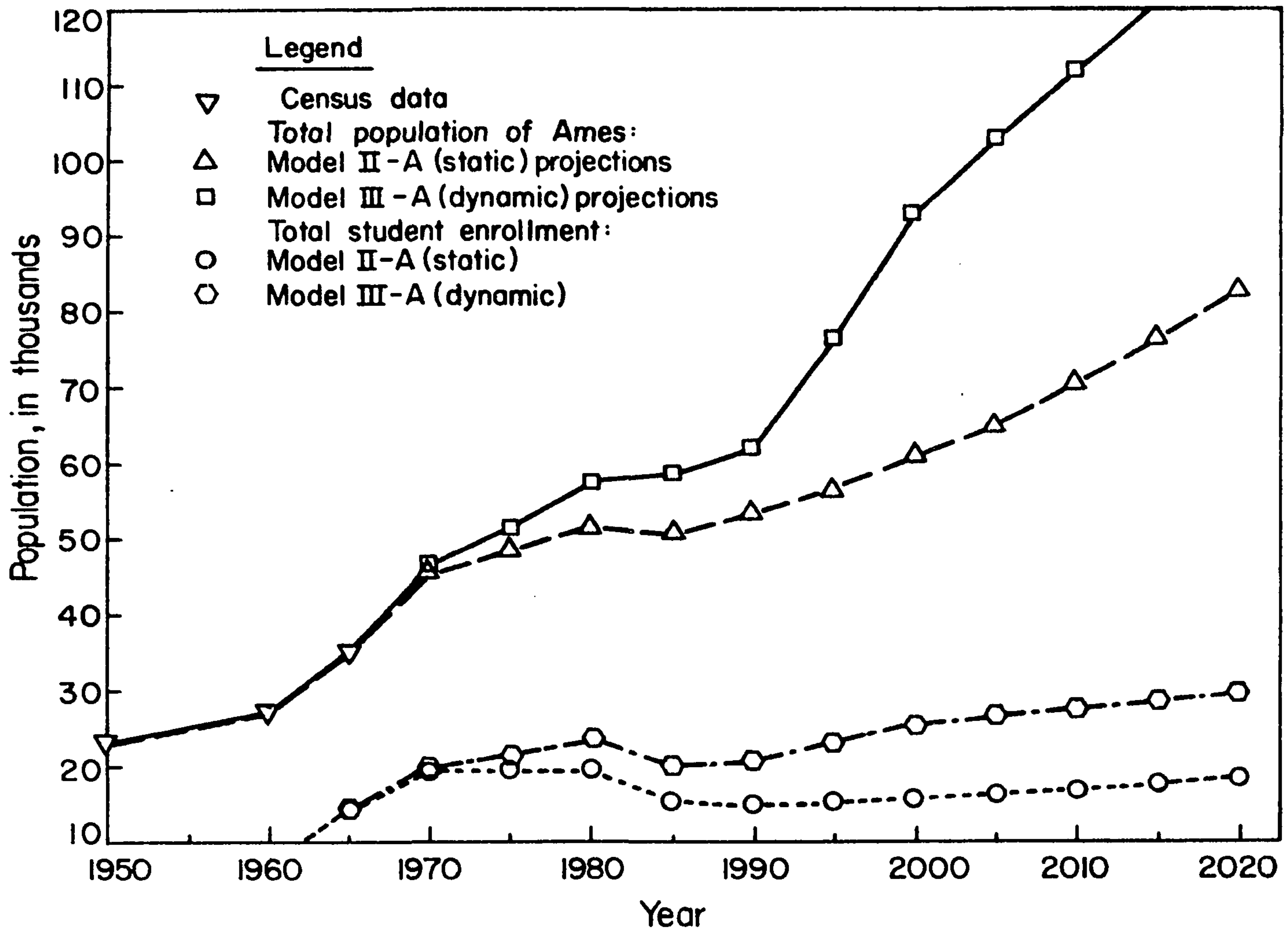

Fig. 31. Population projections for the city of Ames and Iowa State University using Models II and III, Method A, for the period 1970-2020.

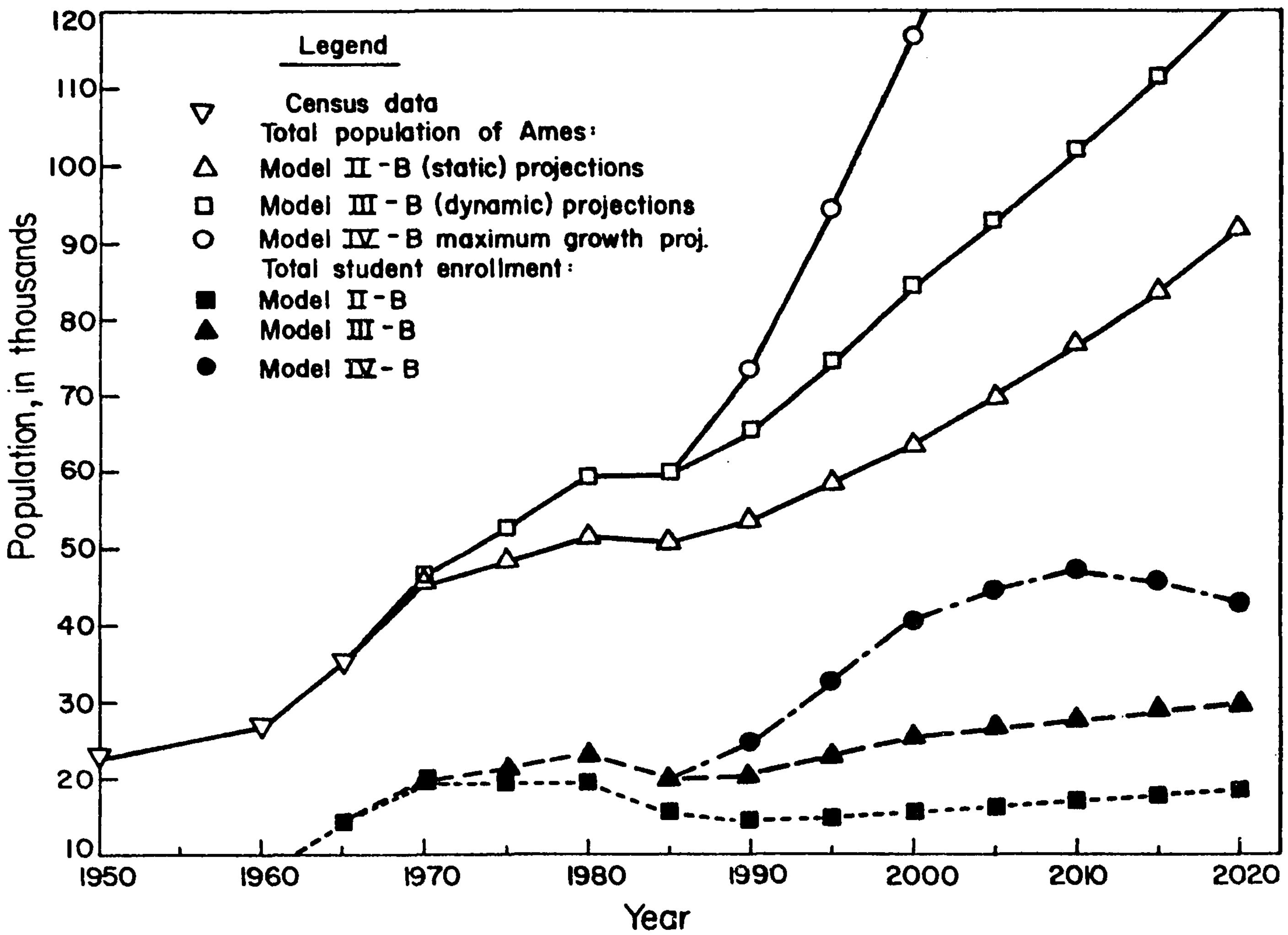

Fig. 32. Population projection for the city of Ames and Iowa State University using Models II, III, and IV, Method B, for the period 1970-2020.

increase indefinitely if the number of college age population students reduces substantially as estimated with these two models. Therefore, straight extrapolation of the present growth rate of the city and university has a very limited application. The results of Models I and II show a tapering off of university enrollment commencing in 1970 and then reaching a definite plateau by 1980. Results beyond the 1990 and 2000 period are very speculative, as past projections of the state population have shown on a state-wide basis (Table 27). Variations in smaller governmental units are more pronounced, and long-term projections may be of doubtful accuracy. Only because of the unique relationship among the local factors at Ames including city and university interdependence, university enrollment versus the college age population group, and the relation of the latter to prior recorded numbers of live births can these current projections to 1990 and 2000 be considered more reliable than otherwise would be the case.

7. Population Projection Model III (dynamic)

a. Introduction of dynamic growth factors The 1958-68 relationship for the percentage of the simulated college freshman age group which attended Iowa State University, as shown in Fig. 28, indicated that an increasing percentage were being attracted to Iowa State. A similar trend was evident in the advancement percentages listed in Table 34, with the relationship for seniors exhibiting the most consistent increase. Therefore, the increasing trend was introduced into a dynamic model, Population Projection Model III.

Dynamic conditions were introduced by using Eq. 100 for the percent of the freshman age group attracted to the university, with an upper limit of 12%. The advancement percentages used in Model II as static quantities were permitted to vary with time in this model until the year 2000, and held constant thereafter. All other conditions remained identical with those adopted for Model II. Therefore, the changes in the previous mathematical model are only in the constant coefficients in Eqs. 102a-102d and 102f-102g. These constant coefficients are replaced with the following time-varying coefficients

a. Coefficient for FREN(N)

$$\begin{cases} 6.96 + 0.13 \times (N - 1960) & 1968 \leq N \leq 2000 \\ 12.0 & N \geq 2000 \end{cases} \qquad (103a)$$

b. Coefficient for SOEN(N)

$$\begin{cases} 0.80 + 0.002 \times (N - 1970) & 1967 \leq N \leq 2000 \\ 0.86 & N \geq 2000 \end{cases} \qquad (103b)$$

c. Coefficient for JREN(N)

$$\begin{cases} 0.77 + 0.002 \times (N - 1970) & 1966 \leq N \leq 2000 \\ 0.83 & N \geq 2000 \end{cases} \qquad (103c)$$

d. Coefficient for SREN(N)

$$\begin{cases} 0.74 + 0.002 \times (N - 1970) & 1965 \leq N \leq 2000 \\ 0.80 & N \geq 2000 \end{cases} \qquad (103d)$$

e. Coefficient for special and graduate students

$$\begin{cases} 0.215 + 0.002 \times (N - 1970) & 1968 \leq N \leq 2000 \\ 0.275 & N \geq 2000 \end{cases} \qquad (103e)$$

As noted above, no other changes are needed. Methods A and B are used to determine the population increases for city residents as explained previously.

b. Discussion and results The results obtained with Model III for methods A and B are listed in Table 37, and the data are plotted in Figs. 31 and 32 along with the results of Model II. In the temporal sense, the dynamic model provides a more optimistic growth pattern for both university and city than does Model II. The population projections obtained using Model III-B compare favorably with the results of Model I-B; the differences for all periods is 10% or less, as inspection of Tables 35 and 37 indicates. Both models show a slower rate of growth for the total city population in the years 1970-80 than would be obtained by linear extrapolation of the 1960-70 trend. Again, a definite plateau is evident for the 1980-85 period.

The enrollment projections for Iowa State University obtained with Model III follow the trends of the other two models, with less reduction in the 1985-90 period than Model II forecasted. On a 5-yr basis, the peak of about 23,000 occurs at 1980 with a sharp drop to the 1985 low of about 20,000. The increase following 1985 is projected on the basis of the modified Series IV-1 Bureau of Census population model which includes a greater increase in population than has been experienced in the last decade or two. Therefore, realization of the results forecast by Model III depends upon continued state growth and a minimum birth rate of 17 per 1,000 population during the remainder of the century. Some compensation may occur in these variables; for instance, if the state population growth lags the projected values but the birth rate again increases, the population age group for college age students could result as forecast. Or the converse could occur. If both lag, then the results obtained with Model II may prevail.

Table 37. Population projections for Ames for period 1970-2020 as determined with Population Projection Model III, relating incoming freshmen to estimated Iowa freshman age group as an increasing percentage (dynamic model)[a]

			Total population			
			Method A		Method B	
Year	Estimated freshman age group	Total student enrollment	City residents	Total	City residents	Total
1965	59,720	14,010[b]	21,400	35,410	21,400	35,410
1970	60,250	19,380	26,780	46,160	26,780	46,160
1975	59,690	21,200	30,040	51,240	31,270	52,470
1980	57,340	23,060	34,880	57,940	36,260	59,320
1985	44,380	19,990	38,370	58,360	39,880	59,870
1990	45,380	20,620	41,000	61,620	44,500	65,120
1995	46,980	23,000	52,910	75,910	51,330	74,330
2000	48,740	25,490	67,350	92,840	58,950	84,440
2005	50,740	26,790	75,960	102,750	66,150	92,940
2010	52,730	27,860	83,860	111,720	73,830	101,690
2015	54,730	28,920	92,620	121,540	82,290	111,210
2020	56,730	29,990	102,220	132,210	91,580	121,570

[a]Compuations based on live births for Iowa, modified state population projections, and derived relationships for enrollment percentages and city-university growth ratios; see text for criteria and application concepts.

[b]Actual, not projected enrollment.

c. <u>A planning period concept</u> The three models developed thus far indicate that the population of the city will reach a plateau value of 50,000 to 65,000 in the 1980's, and will not begin to climb upward appreciably before the last decade of the century. This provides an initial concept of planning periods for the 1970-2000 time span. The 30-yr period can be divided conveniently into two 15-yr planning periods. By planning for the 1985 projected population level, the plateau population requirements (most probably in the 60,000 to 65,000 range) can be met and would be reached early in the 1980's. The plateau period then offers an opportunity to recheck the population projections for the next 15-yr planning period to the end of the century. Because the projections through 1985 have been based on actual live births which have dropped from the 60,000 to 65,000 range down to 45,000 to 50,000 per year, there appears to be little doubt of future adjustments and downtrends in the college enrollment situation. Thus, actual records indicate that the plateau level will in all probability be experienced, with only its magnitude and extent being somewhat indefinite. The values presented in this analysis provide the range within which planning might proceed.

8. Population Projection Model IV (maximum projections)

a. Relationship to state population growth rates This model was included in the final analysis of population projections to provide an upper limit to the potential growth of the city of Ames. It is similar in all respects to Model III except for one variable. The exception is in the state population projection for the period 1970-2000. The population projections given by the Bureau of the Census as Series II-1, as modified in this case study, were used in obtaining projections with Model IV. The data for the state population were listed previously in Table 27, with values increasing from 2.8 million in 1970 to 3.2 million in 1980 and to 4.2 million in 2000. This requires a net annual growth in the state of 40,000 to 50,000 residents. With the number of live births dropping to 45,000 to 50,000 annually and with a mortality rate of 25,000 to 30,000 annually (from 10 to 12 deaths per 1,000 population for many years), the potential for this rapid growth is dwindling rapidly. Today, in all probability, it would require in-migration to achieve the results of Model IV.

The effects of the increased state population growth introduced with the Series II-1 modified projections do not become meaningful in this case study until after 1985. As noted before, this is because the student enrollment has been associated with the number of live births and the resultant 18-yr lag. For the planning period 1970-85, the live births that occurred in 1952-67 (actual recorded births) establish the basis for projecting future populations. Thus, the effect of increasing the state population growth and the number of estimated future live births after 1970 does not affect the study results until the 1990-2000 period.

b. Results for Model IV The application of Model IV was made for method B only, to provide comparative data. The results are included in Table 38 and plotted in Fig. 32 with additional results of Models II and III so that variations can be studied. This "California-type" of population explosion, as forecasted with Model IV, would result in a student enrollment of 40,000 by the year 2000. With the assumed base-growth-multiplier of 1.0 and a 10% additional city residents growth every 5 yr, a tremendous local expansion would occur. The results are shown to indicate, first, that if the increased growth pattern did occur, it would not affect the initial planning period that has been identified, the 1970-85 period. Second, if the university administration maintained its concept of a 25,000 student limit, then the Model IV results have little application also. Because it does not appear that the state population has any real potential of reaching

Table 38. Maximum population projections for Ames for the period 1970-2020, as determined with Population Projection Model IV, using increased growth rates for the total state population[a]

Year	Projected state population, millions	Estimated freshman age group	Total student enrollment	Total population Method B City residents	Total
1965	2.76	59,720	14,014[b]	21,400	35,410
1970	2.80	60,250	19,380	26,780	46,160
1975	3.00	59,690	21,200	31,270	52,470
1980	3.20	57,340	23,060	36,260	59,320
1985[c]	3.45	44,400[c]	19,990[c]	39,880[c]	59,870[c]
1990	3.70	58,100	24,900	48,800	73,700
1995	3.95	69,500	32,700	61,500	94,200
2000	4.20	79,200	40,800	75,800	116,000
2005	–	85,200	44,600	87,100	131,700
2010	–	87,600	47,000	98,200	145,200
2015	–	83,600	45,300	108,000	153,300
2020	–	78,400	42,700	118,800	161,500

[a]Computations based on live births for Iowa, modified state population projections, and derived relationships for enrollment percentages and city-university growth ratios; see text for criteria and application concepts.

[b]Actual, not projected enrollment.

[c]Because of 18-yr lag before live births (based upon state population) become the freshman age group, all values prior to 1985 are the same as for Model III-B; note: values after 2000 are very speculative.

these levels, the results obtained with Model IV were not given further consideration.

9. Composite summary of low, medium and high levels of population projection

The unique relationships which have been identified among the number of live births in Iowa, their relation to the college age population and student enrollment at Iowa State University, and the additional correlation between university growth and city expansion have been expressed in quantitative terms. The development of four population projection models, Models I, II, III, and IV, has permitted forecasting student enrollment under variable conditions; in conjunction with two methods, A and B, of correlating the increase in city residents with increases of student enrollment, forecast of the total population of Ames has been possible.

The forecasts obtained with the four models indicate a distinct leveling off or plateau of the total city population during the period 1980-85, before an increasing trend is again experienced. Recovery as well as extent of the plateau depends in large measure on the growth of the state population and the size of the college age population in the future. This plateau occurring in the growth pattern of the city of Ames indicates a refinement not evident by simple linear extrapolation of the 1960-70 growth trend.

As discussed previously, the forecasts obtained using Models I and III are very similar, differing by less than 10% for Method B. Method I provides the most rapid increase in the population of Ames in the period 1970-85, and the results obtained using Methods A and B differ by less than 2%. A plateau of 65,000 to 70,000 people for the city of Ames occurs with this projection model in the period 1980-90. The results for the period 2000-2020 for all models should be considered most speculative, but serve as an initial basis for making future projections and comparisons.

A summary range of population values was developed from the results of this study, and are listed in Table 39. This provides a low, medium, and high range to correspond to the range provided by the Resources for the Future and the Bureau of Census in the population report of the U.S. Senate Select Committee on National Water Resources. Optimistic planning endeavors should consider the medium to high range as being the most relevant; if state growth falters or declines, including the continuation of the present depressed number of live births, and if in addition the enrollment at Iowa State University begins to level off, then the low range may become a reality. All of the forecasts show the plateau region, and two planning periods have been identified. These are the 1970-85 and 1985-2000 periods, each 15 yr in length. The plateau forecast for 1980-85 provides the "breathing spell" for restudy and reconfirmation of requirements for the next 15-yr planning period.

If more exact determination of these population projections is desired, then additional analysis of the college age population characteristics, out-of-state student population, and the growth relationships between university and the city should be explored. The detailed effect of other business, commercial and industrial growth needs to be studied since it was not specifically included in this analysis. However, the results obtained in the current study are considered sufficient to permit evaluating the requirements for water supply and water pollution control,

Table 39. A composite summary of three levels of population projections for the total population of the city of Ames[a]

Year	Population for indicated range Low level	Medium level	High level
1970	46,000	46,000	46,000
1975	49,000	52,000	55,000
1980	50,000	58,000	64,000
1985	52,000	60,000	66,000
1990	54,000	64,000	70,000
1995	57,000	70,000	76,000
2000	62,000	80,000	90,000

[a]Summarized from results of Models I, II, and III; see Tables 35-38.

and for forecasting the water quality levels in the Skunk River for alternative low-flow conditions.

F. Municipal Demand for Water and Characteristics and Volumes of Waste Water

Analysis of the municipal demand for water at Ames will provide the basis for estimating future water supply requirements and related waste water volumes. Comparison of annual water use and waste water volumes will be made to determine the relationships needed for projecting future requirements for water pollution control facilities. The volumes and concentrations of pollutants that will be discharged to the stream must be evaluated if stream water quality levels are to be forecast. These factors will be the subject of investigation in this section of the case study of the upper Skunk River basin.

1. <u>Water consumption and waste water flows</u>

Because water use logically precedes the discharge of a portion or all as waste water, municipal consumption of water will be the subject of first interest. Also, more data are normally available for water demand than for volumes of waste water produced (U.S. Senate, 1960c-1960j).

The basic data for annual water consumption and municipal waste water volumes are listed in Table 40 (Schworm, 1968; Seidel, 1968). Both the city of Ames and Iowa State University have well fields, water treatment and water distribution facilities. A study of water demand necessarily involves collecting data from each source. The city of Ames in addition to serving its normal municipal customers also provides water service to certain university dormitory complexes and part of the married student housing. This makes it difficult to distinguish the population served by each (again, "noise" in the data). Also, numerous employees working for the university or elsewhere in the city live in surrounding communities, but are water users and waste water producers during the daytime. Similarly, the number of commuting students contribute in a like manner. For the purposes of this study, the per capita water consumption will be based on the census data shown in Fig. 23 for the total city population, using the combined demand as represented by the volume of water pumped to the distribution system of both city and university. The computed per capita water consumption for the period

Table 40. Annual water consumption and waste water volumes for the city of Ames and Iowa State University[a]

Year	Annual water use, mgy City of Ames	Annual water use, mgy Iowa State University	Estimated[b] per capita water use, gpcd	Annual waste water flow, mgy
1951	529	360[c]	105	733
1952	557	370	106	730
1953	550	400	108	663
1954	562	425	110	756
1955	610	450	116	738
1956	631	475	120	665
1957	603	511	118	810
1958	626	512	119	845
1959	643	492	117	991
1960	647	482	114	1,107
1961	717	479	114	1,137
1962	770	466	112	1,220
1963	818	552	118	1,146
1964	849	569	116	1,106
1965	950	609	122	1,234
1966	1,046	643	125	1,235
1967	1,144	660	126	1,208

[a]Municipal data obtained from annual reports of the city of Ames (Seidel, 1968); university data obtained from records of the Physical Plant (Schworm, 1968).

[b]Population values obtained from Fig. 23.

[c]Data for the university pumping rates not available for period 1951-55; values estimated from approximate relationships between city and university demands for other period.

1951-1967 is included in Table 40, along with the basic water demand and waste water data.

The data are also shown in Fig. 33. Comparative precipitation data are also plotted (U.S. Weather Bureau, 1967), to illustrate the effect of drought periods or periods of excess precipitation on water demand and on waste water volumes. The period 1952-56 was a severe drought period in southern and central Iowa (except for severe summer floods in 1954), as was shown in the low-flow analysis. The annual precipitation data show that above normal precipitation occurred during two periods, 1959-1961 and 1963-1965. The trend of annual water demand shown in Fig. 33 illustrates two effects. First, the increase in water demand is similar to the population growth trend evidenced previously for the city and the university (Fig. 23). The increasing trend since 1960 is evident in both figures. Second, the plateau which began in 1957 coincides with the period of increased precipitation (and related cooler temperatures) as well as the brief decline in student enrollment (see Fig. 25).

The recorded waste water volumes have fluctuated even more widely than have the water demand values. For 3 yr, 1962 through 1964, the waste water volume almost equalled the water demand. Additional infiltration into the sewers from groundwater and from basement and roof drains during periods of excess precipitation are considered to be the primary reasons for this increase. The small increase in waste water volumes compared to the increase in water demand since 1962 is noteworthy. Weather conditions have varied from normal to below normal in

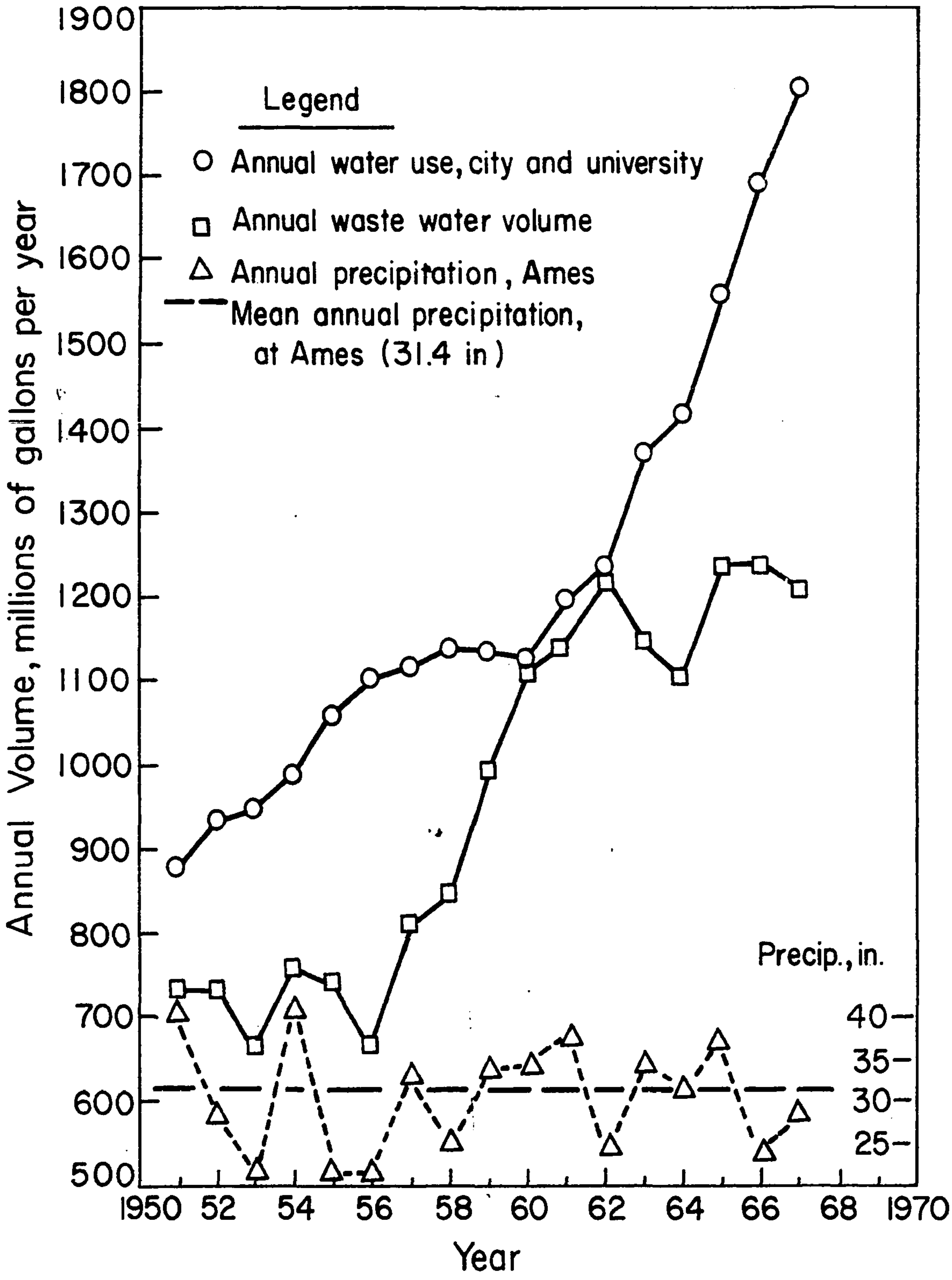

Fig. 33. Annual water demand and waste water volumes recorded at Ames, Iowa, for the period 1951-67.

precipitation and could partially be the cause. The use of water for cooling by the municipal and university steam-electric generating plants has increased substantially since 1960, and some consumptive use by these two plants is probable. However, detail investigation of this anomaly between water use and waste water volumes was not pursued further.

The computed daily per capita water consumption data are plotted in Fig. 34. If the temporal variations in demand are compared with the precipitation trends shown in Fig. 33, it is observed that the demand for water has increased during drought periods (accompanied by higher temperatures) and has decreased during periods of excess precipitation (and lower temperatures presumably). The general increase in per capita consumption is evident in Fig. 34, following national trends (U.S. Senate, 1960c, 1960d; U.S. Geological Survey, 1969). Some recent trends and estimates attribute about 60 to 65 gpcd for strictly domestic household purposes (250 gpd for a family of 4), with the remainder representing various municipal, commercial and industrial uses.

Estimates for 1980 and 2000, made for the U.S. Senate Select Committee on National Water Resources (U.S. Senate, 1960c), included values for the upper Mississippi River basin. The representative values are shown in Fig. 34, and a linear relationship through these points agrees closely with the high points of the Ames data. Therefore, it appears reasonable to assume that this relationship will be applicable for drought year conditions (for which stream water quality will be most critical, in view of the 7-day, 10-yr low-flow criteria) in making projections for the

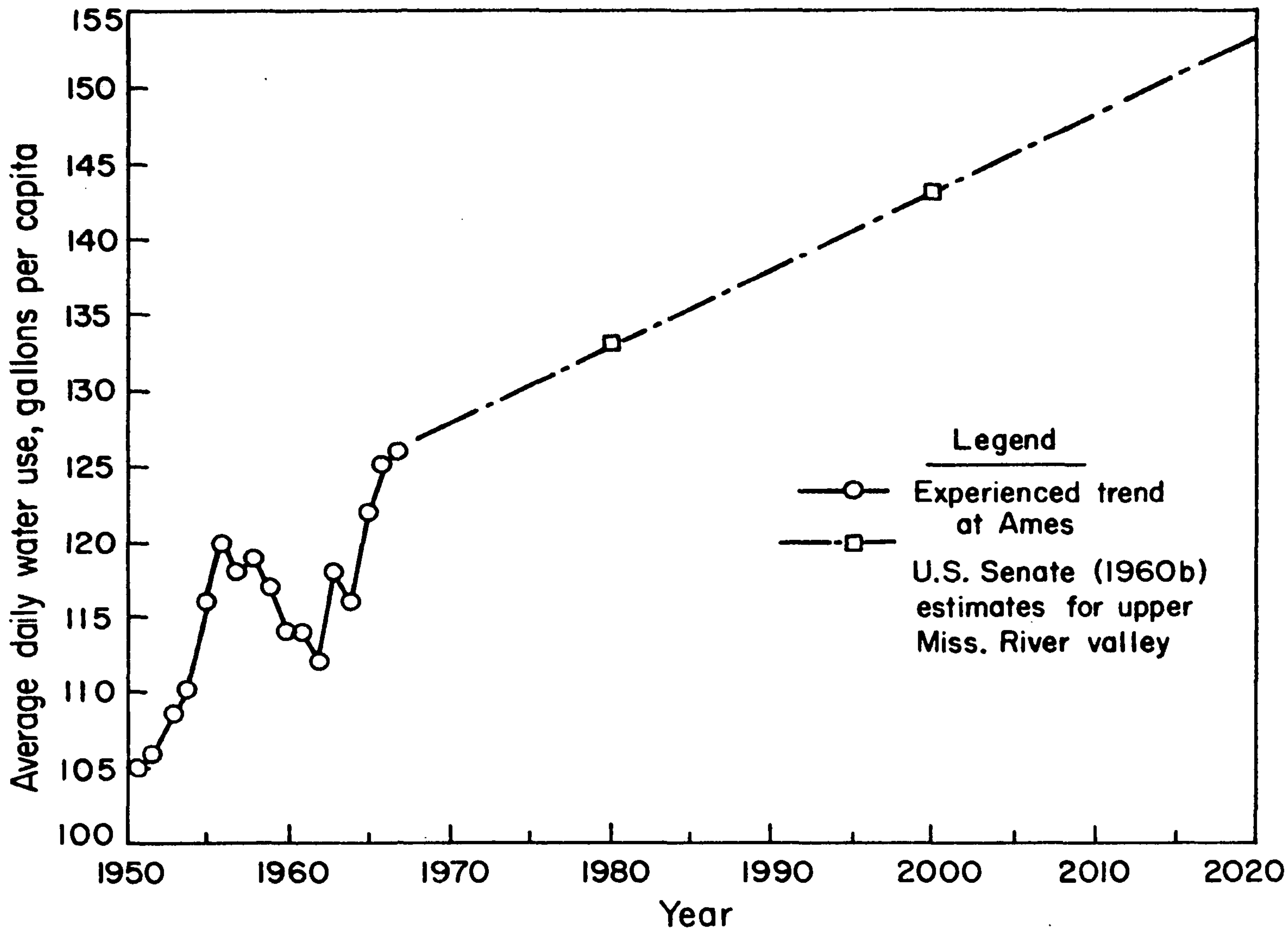

Fig. 34. Observed and projected per capita daily water consumption for the city of Ames, Iowa.

future. During periods of excess precipitation and related cooler temperatures, a reduction of 10 to 15 gpcd may be expected.

2. Projections of drought year waste water volumes

For the purposes of the case study, water demand is of primary value in obtaining estimates of future waste water volumes. Knowledge of the volumes of waste water, combined with the concentrations of potential pollutants and treatment efficiencies, will permit evaluating stream loadings. Or, in a corollary sense, knowledge of permissible loadings will specify the degree of treatment required.

Because drought periods are of the greatest concern in this study, average values or average trends are not sufficient. Also, since both summer and winter periods were identified in the low-flow analysis as being pertinent in a stream water quality study, some breakdown of annual data into seasonal categories was desired. However, extensive analysis of monthly variations was beyond the scope of this study.

Analysis of the relationship between water demand and waste water volumes for both observed data and modified data to represent drought conditions is summarized in Table 41. For the period 1953-67, waste water volumes as a percentage of water demand ranged from a low of 60% in 1956 to almost 99% in 1962. The 15-yr average is 79%. If the five wettest years are excluded, an average of 72% is obtained. A better estimate of drought year flows was approximated next using the graphical trends illustrated in Fig. 33. A lower boundary curve was introduced which represented an average trend of drought period waste water flow. Only the year 1956 was below the simulated lower boundary curve, and

Table 41. Relationship of annual waste water volumes with water demand at Ames, Iowa

	Experienced values[a]			Drought year approximations[b]	
Year	Water demand, mgy	Waste water volume, mgy	Waste as percent of water	Waste water volume, mgy	Waste as percent of water
1953	950	663	69.8	650	68.5
1954	990	756	76.5	690	69.8
1955	1,060	738	69.6	730	68.9
1956	1,105	665	60.1	770	69.7
1957	1,114	810	72.6	810	72.6
1958	1,138	845	74.3	850	74.7
1959	1,135	991	87.5	890	78.5
1960	1,129	1,107	98.1	930	82.5
1961	1,196	1,137	95.1	970	85.4
1962	1,236	1,228	98.8	1,010	81.9
1963	1,370	1,146	83.7	1,050	76.7
1964	1,418	1,106	77.8	1,090	77.0
1965	1,559	1,234	79.2	1,130	72.5
1966	1,689	1,235	73.2	1,170	69.4
1967	1,804	1,208	67.0	1,210	67.1

[a]Data compiled from value of Table 40.

[b]Lower boundary for drought period concept, based on annual waste water relationships shown in Fig. 33.

the values approximated with this curve are listed also in Table 41. The 15-yr average for the drought period concept is 74% of the observed water demand. Because water demand decreased during the wetter periods in 1959-1963, excluding these values gave a 10-yr average of 71%. The driest 6 yr were under 70%. It was concluded that 70% was a typical annual value that would suffice for projecting future waste water volumes for water quality control purposes. This low a value also reflects the potential consumptive use of water through evaporative effects in the cooling towers of local steam-electric generating plants, as indicated at the beginning of this section.

3. Seasonal variations in waste water volumes

a. Results of studies at Ames   Seasonal variations in waste water flow (summer versus winter) were evaluated next. Data from a study by Hutchinson and Baumann (1958) indicated monthly variations of - 14% to + 19% of average annual waste water flow volumes. The high value occurred in May, a month in which low stream flows will hardly be expected. For drought period application, a seasonal variation in waste water volumes of ± 10% was adopted. This yields a factor of 0.77 for estimating waste water volumes in summer, and 0.63 for winter periods; the annual arithmetic average remains at 0.70 or 70% of the projected water demand. If an approximate sinusoidal pattern is adopted, then values of 70% would occur in the fall and again in late winter or very early spring.

b. Additional mathematical relationships   The observed seasonal variations in water demand and waste water volumes indicated that a mathematical relationship might exist between the two variables. This relationship was evaluated for potential application in relating waste water volumes to water use projections. The assumptions for this analysis require that the seasonal variations during a year approximate a sinusoidal or square wave type of curve, or

1. The arithmetic average of seasonal variation (summer versus winter) in waste water volume should be equal to the annual average waste water volume, expressed as the percent of average annual water use (70 percent in the case study at Ames).

2. The positive increase above the average waste water volume, occurring in the summer season, should equal the decrease experienced during the winter season (equal amplitude about the mean).

Terminology for the development of the pertinent relationships between the seasonal increases in water demand and waste water volumes is as follows:

a = fraction of annual water use which becomes waste water, as an annual average (0.70 or 70 percent adopted for Ames).

b = experienced or assigned seasonal variation (amplitude) in water demand (10 percent adopted for Ames).

c = experienced or assigned seasonal variation (amplitude) in waste water volume, with the total range being 2c or twice the amplitude (varies from 10 percent to a maximum of 20 percent for Ames).

X = fraction of summer water demand that becomes return waste water (nonconsumptive portion).

Y = fraction of winter water demand which becomes return waste water (again, the nonconsumptive portion).

Z = average annual water demand, in terms of mgy, gpcd, or gpd.

The two mathematical expressions which are required to comply with the two assumptions are, for the arithmetic average and the correct amplitude for seasonal variations

$$\frac{X(1 + b)Z + Y(1 - b)Z}{2} = aZ \qquad (104a)$$

and

$$X(1 + b)Z - Y(1 - b)Z = 2acZ \qquad (104b)$$

Solution of the simultaneous equations yields

$$X = a\ \left(\frac{1 + c}{1 + b}\right) \qquad (105a)$$

$$Y = a\ \left(\frac{1 - c}{1 - b}\right) \qquad (105b)$$

At Ames, the coefficients for the observed relationships are:

a = 0.70; b = 0.10; c varies, 0.10 average variation to 0.20 maximum variation.

For the given values of a and b, and with c = 0.10,

$$X = 0.70 = Y$$

and the fraction of waste water in summer, in terms of annual demand is

$$X(1 + b)Z = 0.70(1 + 0.10)Z = 0.77Z$$

and the fraction of waste water in winter, in terms of annual demand is

$$Y(1 - b)Z = 0.70(1 - 0.10)Z = 0.63Z$$

with an average waste water volume of 0.70Z, using Eq. 104a.

For the given values of a and b, but with c = 0.20,

$$X = 0.764 \text{ and } Y = 0.622$$

and the fraction of waste water in summer, in terms of annual demand is

$$X(1 + b)Z = 0.764(1 + 0.10)Z = 0.84\ Z$$

and the fraction of waste water in winter, in terms of annual demand is

$$Y(1 - b)Z = 0.622(1 - 0.10)Z = 0.56\ Z$$

and the average is again 0.70 Z.

These examples illustrate the several relationships which exist among these variables, the annual water demand and its seasonal variations and the annual waste water volume (as an average percent of annual water demand) and its seasonal variations. These relationships are useful in evaluating the reasonableness of assumed values or in checking the implications of observed values. Equations 105a and 105b can be used to illustrate limiting values of X and Y. As long as b = c, the proportion of actual summer and winter water demand returned as waste water remains the same (X = Y = a), although more waste water volume is returned in the summer because of the factor b. For values of c larger than b, a higher proportion of waste water is returned in the summer than winter, and the winter proportion becomes very low for c = 2b, as indicated above. For values of c less than b, a higher proportion of waste water is returned in winter than summer. Probably, in view of the proportionality value a and variation coefficients b and c which would be common for most municipalities, values of b and c if not equal would not differ by more than twofold. The results using the observed data at Ames show that during drought periods, the return waste water is from two-thirds to three-fourths of the water demand, thus indicating a substantial consumptive use during such dry weather periods.

4. Projected values of waste water volumes for the case study

Projection of drought year waste water volumes were made for the period 1970-2020, recognizing that the estimates beyond 2000 are quite speculative and serve as planning indicators only. The results are listed in Table 42. The summer drought year waste water flows increase from 4.5 mgd in 1970 to 8.8 mgd in the year 2000 with ultimate values of 13.6 mgd for 2020. The winter drought year flows increase from 3.7 mgd in 1970 to 7.2 mgd in 2000 and a rough estimate of 11.2 mgd in 2020. These estimates were made using the population projections of Model I-B, which provide the greatest population growth rates during the period 1970-85. This also is the medium to high level of ranges shown in Table 39, and provides an appropriate optimistic outlook for urban growth at Ames. Wet weather flows would be greater than these drought estimates, and would be needed for determining the hydraulic capacity of waste treatment facilities. However, the dry weather flows are of interest in the case study since they provide the greatest stress on the stream system for the purpose of evaluating water quality.

5. Pollution characteristics of the waste water

a. Basic data The predominant characteristic of the waste water which is of importance in the case study is the organic waste load,

Table 42. Projected waste water volumes for drought period analysis at Ames, Iowa

Year	Projected population of Ames[a]	Estimated avg. daily water demand[b] Per capita, gpd	Total mgd	Estimated drought year waste water volume, mgd[c] Summer	Winter
1970	46,300	127.5	5.903	4.546	3.719
1975	54,700	130.	7.111	5.475	4.480
1980	63,800	132.5	8.454	6.509	5.326
1985	64,900	135.	8.762	6.746	5.520
1990	67,900	137.5	9.336	7.189	5.882
1995	74,000	140.	10.36	7.977	6.527
2000	80,700	142.5	11.50	8.855	7.245
2005	88,000	145.	12.76	9.825	8.039
2010	97,000	147.5	14.31	11.02	9.014
2015	106,000	150.	14.90	12.24	10.02
2020	116,000	152.5	17.69	13.62	11.15

[a]Values from Population Projection Model I-B, Table 15.

[b]Obtained from report of U.S. Senate (1960c) for upper Mississippi River valley and from Fig. 34.

[c]Based upon relationship developed between water demand and waste water volumes, using overall 77% for summer, 63% for winter.

stated in terms of its biochemical oxygen demand (BOD). Both nitrogenous and carbonaceous organic loads are of interest, and need to be evaluated. The normal carbonaceous organic load will be evaluated first, and the nitrogenous load estimated through the ammonia levels. Because all laboratory tests and data collected and reported by the city water pollution control plant are for BOD_5 (Standard Methods, 1965), the correlations and summaries presented in this section will be in terms of the same parameter.

Although water demand and waste water volumes are monitored with continuous recorders, the organic waste load is only measured in normal plant operation at periodic intervals. Once-weekly sampling is standard practice, with the weekly sample being made up of a composite sample for the 24-hr daily period selected for use. At Ames, some additional sewer siphon and outfall problems occur during flood periods and frequently the plant is bypassed. Plant operation methods include periodic filter-flooding techniques to control filter flies, and this affects plant operation and treatment efficiencies during summer periods. For these several reasons, precise temporal evaluation of the total organic waste load is not possible. At Ames, the concentration of organic waste loads for the National Animal Disease Laboratory (NADL) is determined separately, and the at-plant record includes the total of all municipal domestic and industrial wastes. This includes the waste water from the university also.

The plant operation data for 1966-67 indicated that about 5% of the total waste water volume originated at the NADL. The BOD_5 varies from 100 to 200% of the combined organic waste strength, with an average of approximately 150%. Evaluation of the carbonaceous organic waste load in terms of per capita values indicated that the commonly accepted values of 0.17 to 0.18 pcd of BOD_5 were sufficiently precise for projecting future waste loads of the municipal domestic portion. Methods were then developed for projecting the industrial waste loads to coincide with the increased water consumption previously forecast.

b. <u>Techniques for estimating future waste loads and concentrations</u> A combination of municipal domestic and industrial waste contributions were selected for use in evaluating the stream water quality problems under future growth patterns. Industrial waste flows were increased from the 5% experienced as of about 1970 to a maximum of 15% of the total waste water flow in 2020. This represents an increase of 2% per decade. It effects a reduction of the municipal contribution of the total waste water flow from 95 to 85%. This is equivalent to allocating most of the increase in water demand to industrial expansion, a trend also forecast nationally (U.S. Geological Survey, 1969). In addition, the organic waste strength of the estimated industrial flow was increased from a factor of 1.5 in 1970 to a value of 2.0 in the year 2020, or a 10% increase per decade.

The industrial waste load contribution was converted to an equivalent population in terms of pcd of BOD_5 and concentration by introducing the following mathematical relationships existing among the several variables:

1. For each selected 5-yr period, let QD = per daily capita water demand as previously estimated and POP = projected population for corresponding year. SESFCT will represent the seasonal factor, for return waste water as a proportion of QD:

$$SESFCT = a(1 + c) = X(1 + b) \qquad (106a)$$

for summer conditions, and

$$SESFCT = a(1 - c) = Y(1 - b) \qquad (106b)$$

for winter conditions, using Eqs. 104 and 105.

2. The BOD_5 concentration in the municipal domestic portion of the total waste water flow is given by

$$MUNBOD = \frac{0.18 \times 10^6}{QD \times PMUN \times SESFCT \times 8.34} \qquad (106c)$$

where

MUNBOD = concentration of BOD_5 for the municipal portion of the total waste water flow, ppm or mg/l

PMUN = the percent of QD that is municipal domestic waste and not industrial, and the other terms were defined previously.

3. The industrial waste concentration, INDBOD, in ppm or mg/l is computed by

$$INDBOD = MUNBOD \times IWSFCT \qquad (106d)$$

where

IWSFCT = industrial waste strength factor, a measure of how much more concentrated the industrial organic waste is in comparison to the domestic waste, and varying from 1.5 to 2.0 in the case study.

4. The industrial waste water volume is given by

$$QIND = (1 - PMUN) \times QD \times SESFCT \qquad (106e)$$

5. The population equivalent of the industrial waste, PEIND, in terms of pounds of BOD per capita per day (pcd), is computed using Eqs. 106d and 106e,

$$\begin{aligned} PEIND &= \text{concentration} \times \text{flow} \\ &= INDBOD \times QIND \\ &= 0.18 \times IWSFCT \times \frac{1 - PMUN}{PMUN} \qquad (106f) \end{aligned}$$

6. The industrial waste strength factor, IWSFCT, for the design period used in projecting populations is then

$$IWSFCT = 1.5 + 0.01 \times (N - 1970) \qquad 1970 \leq N \leq 2020 \qquad (106g)$$

7. The percent of the total waste flow which will be municipal without the specified industrial load is expressed as

$$PMUN = 0.95 - 0.002 \times (N - 1970) \qquad 1970 \leq N \leq 2020 \qquad (106h)$$

8. The total BOD_5 in terms of per capita daily mass amount for both municipal and industrial is then

$$PETOT = 0.18 + PEIND \qquad (106i)$$

9. The total daily load of BOD_5 delivered to the water pollution control plant by the projected population, POP, is

$$TBOD = POP \times PETOT \qquad (106j)$$

10. The equivalent concentration of BOD_5 for the TBOD value is computed by

$$CONBOD = \frac{TBOD \times 10^6}{QD \times SESFCT \times 8.34} \qquad (106k)$$

where

CONBOD = concentration of BOD_5 in the total waste water flow in ppm or mg/l.

This technique permits computing the total daily organic waste load independent of the volume of waste water, and allows the total load to be computed easily and rapidly for any population projection.

c. Projected organic waste loads for future city growth The results of this analysis, using Eq. 106, are listed in Table 43. The combined carbonaceous organic waste loads (municipal and industrial) are tabulated as per capita values, total organic loading and as concentration of material, using the population projections of Model I-B for the latter two. The results show that the equivalent per capita organic loading increases from 0.194 pcd in 1970 to a value of 0.244 in 2020. The concentration of BOD_5 in the estimated waste water volumes increases only slightly during the period. This illustrates again the fact that most of the increased water demand is expected to be used in industrial categories with higher associated BOD contributions. If such increases do not materialize, but water demand increases at the rates forecasted, then the BOD concentration would decrease accordingly. As indicated in Table 43, BOD_5 concentrations would be in the range of

Table 43. Projected organic waste loads[a] as biochemical oxygen demand, 5-day, 20 deg C, for Ames, Iowa

Year	Municipal waste flow, percent of total	Industrial waste load: Flow, percent of total	Industrial waste load: Strength factor	Industrial waste load: Load, lb/pcd	Combined organic loading: lb/pcd	Combined organic loading: lb/day[b]	Concentration, mg/l: Summer	Concentration, mg/l: Winter	Estimated population equivalent[b]
1970	95	5	1.50	0.0142	0.1942	8,990	237	290	50,000
1975	94	6	1.55	0.0178	0.1978	10,820	237	290	60,000
1980	93	7	1.60	0.0217	0.2017	12,870	237	290	71,000
1985	92	8	1.65	0.0258	0.2058	13,360	237	290	74,000
1990	91	9	1.70	0.0303	0.2103	14,280	238	291	79,000
1995	90	10	1.75	0.0350	0.2150	15,910	239	292	88,000
2000	89	11	1.80	0.0404	0.2204	17,790	241	294	98,000
2005	88	12	1.85	0.0454	0.2254	19,840	242	296	110,000
2010	87	13	1.90	0.0511	0.2311	22,420	244	299	125,000
2015	86	14	1.95	0.0571	0.2371	25,130	246	301	140,000
2020	85	15	2.00	0.0635	0.2435	28,250	249	304	157,000

[a]Projections based upon observed trends of industrial waste loads, and attributing most of the increased water demand to industrialization (see text for computation methods).

[b]Population based upon Projection Model I-B.

235 to 250 in the summer but due to lower seasonal water consumption would increase to a range of 290 to 305 mg/l in the winter. The adjusted population equivalent for Ames using Population Projection Model I-B and including the increased industrial waste load is listed in the last column in Table 43. These data indicate that both the organic load in pounds of BOD_5 and the associated population equivalent will double by the end of the century.

Using the techniques outlined in this and the previous sections, the total carbonaceous organic waste loads, both municipal and industrial, were determined and values plotted in Fig. 35 for the three population projection models, I, II, and III, using Method B for estimating the city residential growth accompanying the university growth trend. The difference between the results obtained with Models I and III is less than 10%. A plateau is evident here also, similar to the population plateau. This occurs despite an increasing industrialization trend permitted in the study methods.

The plateau relationships evident in Fig. 35 confirm the desirability of using two planning periods for the future, the 1970-85 and 1985-2000 periods. The results for the long-term period 2000-2020 are guidelines only at this time and must be reevaluated during future planning periods to provide better forecasts for events that are this far in the future. For the 1970-85 period, the design value of BOD_5 becomes the general plateau value of 13,000 to 14,000 lb of BOD_5 daily, or a PE of 70,000 to 80,000 people.

d. Other waste water characteristics The primary constituents of the waste water which are potential pollutants in the case study of

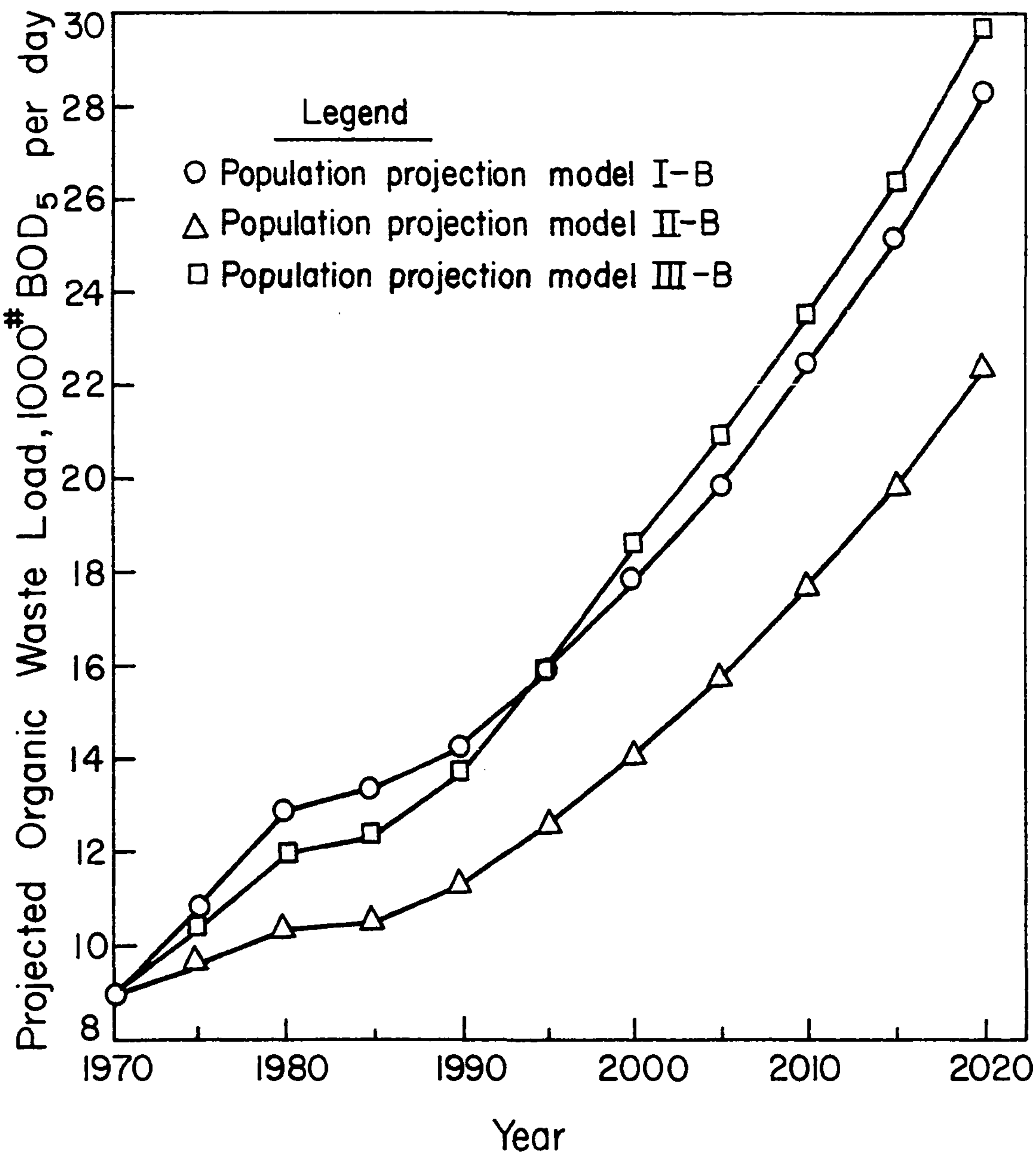

Fig. 35. Projected organic waste loads for three population projection models at the city of Ames, Iowa.

the Skunk River at Ames are BOD, suspended solids (SS), ammonia and organic nitrogen as the nitrogenous organic waste load for oxygen consumption, other forms of nitrogen (especially nitrates) and soluble inorganic phosphate ($PO_4^{\equiv}$) as indicators of the algae growth potential in low-flow periods. Data collected by the city of Ames at the water pollution control plant are listed in Table 44 (Seidel, 1968). The values shown, if compared to the average values shown in Table 1, indicate that the concentrations follow those normally expected in domestic sewage from an average community. If anything, the values are on the lower side of the ranges given.

6. Efficiency study of the existing water pollution control plant

a. Design features   The existing water pollution control plant at Ames, Iowa, was designed in 1948 (Mullinex, 1948) and constructed in the period 1949-50. The plant was designed for a population of 25,000 and the following design features were given for the hydraulic and organic loadings.

Sewage flow
- Average flow 2.2 mgd or 1,530 gpm
- 4-hr maximum flow 2.97 mgd or 2,070 gpm
- 1-hr maximum flow 3.85 mgd or 2,680 gpm

BOD_5, raw sewage

Estimated daily contribution	4,220 lb per day, or 2,2 mgd at 230 mg/l
Plant design	4,560 lb per day

Secondary treatment unit

Three standard rate trickling filters

Total surface area	0.99 acres
Total volume	7.92 ac ft

Loading, for 60 percent organic loading (40 percent removal in primary treatment units)
345 lb BOD_5 per ac ft daily

Table 44. Selected characteristics of the waste water at the Ames water pollution control plant[a]

Item	Amount in lb per day for indicated year and category: Calendar year 1966, Annual average	Calendar year 1966, Month with maximum	Calendar year 1966, Month with minimum	Calendar year 1967, Annual average	Calendar year 1967, Month with maximum	Calendar year 1967, Month with minimum
BOD_5						
Raw sewage	4,800	5,600	3,670	6,100	7,900	4,400
Final effluent						
Untreated	1,460	2,300	630	1,530	2,650	840
Pasteurized	850	2,070	260	1,150	1,960	510
Suspended solids						
Raw sewage	4,550	5,700	3,750	4,500	6,250	3,000
Final effluent	530	780	190	650	1,140	310
Ammonia nitrogen, as N						
Raw sewage	600	700	440	730	840	520
Final effluent	470	710	210	460	750	250
Nitrate nitrogen, as N						
Raw sewage	70	140	35	15	30	5
Final effluent	155	280	25	110	170	35
Phosphates, as PO_4						
Raw sewage	600	660	540	630	740	540
Final effluent	680	760	600	785	870	680

[a]Source: Annual reports of Ames water pollution control plant (Seidel, 1968).

Table 44. Cont.

Item	Calendar year 1966 Annual average	Calendar year 1966 Month with maximum	Calendar year 1966 Month with minimum	Calendar year 1967 Annual average	Calendar year 1967 Month with maximum	Calendar year 1967 Month with minimum
	Amount in lb per day for indicated year and category					
COD						
Raw sewage	8,200	10,000	7,000	10,400	13,400	8,600
Final effluent	2,400	2,700	2,300	2,440	3,070	1,800
Waste water flow, million gallons per day	3.39	4.5	2.7	3.31	4.4	3.1

b. Operating data for the plant The annual reports of the water pollution control plant list the annual treatment efficiencies obtained through plant operation. These data are included in Table 45. Also listed are estimated values of the population equivalent based on census population data and the equivalent population for the industrial wastes of the NADL for the period 1961-67. These were determined from waste water flows and waste concentrations from the NADL.

The plant efficiency data are plotted in Fig. 36. According to the design data and the population equivalent values shown in Table 45, the plant capacity was reached in 1955. The efficiency trend is definitely downward, as indicated by the BOD_5 relationship, and plant replacements by 1972 (as requested by the Iowa Water Pollution Control Commission) appear to represent a realistic need.

Although removal of suspended solids remained high (above 90%) until a PE of 34,000 to 36,000 was reached, a definite trend downward exists in the percent removal of BOD_5 since the plant was placed in operation and the population began expanding rapidly. The experienced trends were evaluated through regression analysis. For the removal efficiency of BOD_5, the data were correlated both with annual dates and with the PE values previously estimated. The regression equations obtained were:

$$Y = 83.76 - 0.72 \times (N - 1950); \qquad 1950 \leq N \leq 1970 \qquad (107a)$$

where

Y = percent BOD_5 removal, and

N = year for which a value of Y is to be computed.

Table 45. Plant removal efficiencies reported by the Ames water pollution control plant for the period 1951-67[a]

Year	Removal of BOD_5, percent	Reduction of suspended solids, percent	Estimated population equivalent, PE[b]
1951	82	90	23,400
1952	81	89	23,800
1953	83	91	24,200
1954	82	87	24,600
1955	75	88	25,000
1956	81	90	25,400
1957	74	89	25,800
1958	86	92	26,200
1959	78	87	26,600
1960	87[c]	95[c]	27,000
1961	79	90	29,000
1962	75	90	31,000
1963	70	90	33,000
1964	66	87	35,000
1965	75	90	37,000
1966	70	88	40,000
1967	75	84	43,000

[a]Source: Summarized from annual reports of the water pollution control plant to the City Manager, Ames (Seidel, 1968).

[b]Determined from population estimates and NADL waste water contributions (Seidel, 1968).

[c]Summer months only.

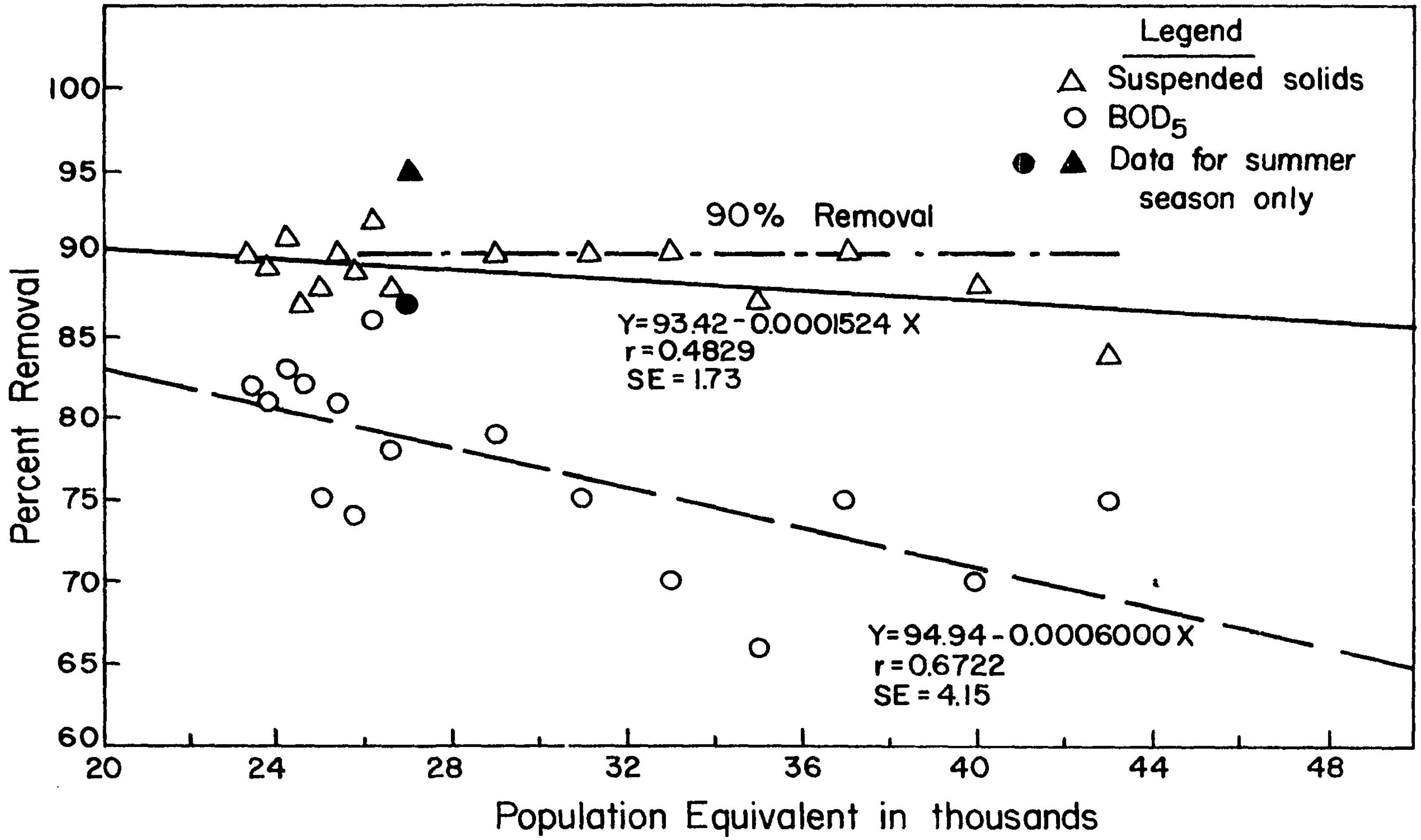

Fig. 36. Efficiency of the water pollution control plant at Ames, Iowa, for the period 1951-67.

The correlation coefficient was 0.668 and the standard error of estimate was 4.17.

and

$$Y = 94.94 - 0.000600 \times (PE) \qquad (107b)$$

where

PE = population equivalent contributing wastes to the plant, and

Y was defined above.

The correlation coefficient was 0.672 and the standard error of estimate was 4.15.

For the suspended solids in the waste water, the following regression equations were obtained:

$$Y = 90.1 - 0.13 \times (N - 1950) \qquad 1950 \leq N \leq 1970 \qquad (108a)$$

where

Y = percent removal of suspended solids (SS), and

N = year for which Y is to be estimated.

The correlation coefficient was low, 0.34, but with a standard error of estimate of 1.86. Based upon PE values,

$$Y = 93.42 - 0.000152 \times (PE) \qquad (108b)$$

The correlation coefficient remained low, 0.483, and the standard error of estimate was 1.73. The plotted data illustrate that an average value of 90% would suffice for PE values of less than 34,000.

The relationships that have been derived will permit existing conditions and plant efficiencies to be introduced into stream water quality studies. For the existing plant, a summer increase in efficiency of 5% appears to be an experienced value which might be used in stream evaluation, and a winter decrease of like amount might be expected.

Effluent studies to be evaluated in the next chapter will assist in confirming the plant data analyzed in this section.

XI. CHARACTERISTICS OF EFFLUENTS FROM WATER POLLUTION CONTROL PLANTS

A. General Considerations

The organic waste data obtained from the records of the city of Ames and reported in the previous chapter were primarily those associated with determination of the 5-day biochemical oxygen demand (BOD_5). Although this is a standard test in plant operation and sanitary engineering practice (both as design criteria and in analytical studies), it provides little if any information concerning temporal rates of oxygen demand during the 5-day period or for subsequent days. Equation 13, the first-order mathematical model for representing the BOD progression with time, contains two unknowns, k (or K_1) and L_a. A single observation such as the BOD_5 value yields no quantitative information about either unknown, despite the assumed initial condition of $y = 0$. A minimum of two observations in a time series is required to yield singular solutions for k and L_a. If additional values in a time series are obtained, then the coefficient, k, and ultimate value, L_a, can be evaluated using Eqs. 16-18, selecting the desired model.

Thomas (1948) emphasized, first, the need for determining the ultimate biochemical oxygen demand, BOD_u, and using it as the value of L_a in stream pollution studies (as applied in Eqs. 45, 46 or 74), and second, the corollary requirement for long-term BOD laboratory analyses of raw waste water and effluents. Various researchers (Orford et al., 1953; Orford and Ingram, 1953; Woodward, 1953; Busch, 1958; Fisichelli and Palomba, 1960; and Schroepfer et al., 1960), as noted previously, have obtained results showing a variation of k and L_a with the time period of analysis, as well as between various sources of domestic wastes. Values of k for raw sewage have been greater than those observed for final effluents. These more recent results have been included in a recently published text in sanitary engineering (Fair et al., 1968, p. 33-16).

These additional factors and concepts including temporal BOD data were not available at Ames, or for other municipalities in the upper basin. Therefore, this phase of the research program was devoted to a study of the characteristics of effluents from typical water pollution control plants in the region. Three objectives were outlined for this phase of the case study. First, study was to be made of the BOD characteristics of the waste effluents in terms of both carbonaceous and nitrogenous oxygen demand. Second, by selecting effluents from typical water pollution control plants representing different types of secondary treatment processes, the variations in removal of organic constituents and other substances could be ascertained. Third, the availability of a time series of BOD data for these several effluents would enable the adequacy of the first-order mathematical model for BOD progression to be evaluated in detail.

Experimental studies of BOD progression were made of effluents from three types of secondary waste treatment processes used in the region close to Ames. These included the effluent from the standard rate trickling filter plant at Ames, the activated sludge plant at Marshalltown, and a waste stabilization pond at Jewell (primary and secondary treatment). In addition, data were obtained for a sample from an agricultural waste lagoon (serving a confined swine feeding unit at Iowa State University). In the mathematical analysis, additional data for raw domestic sewage as reported in research literature were used to provide further confirmation of the laboratory results obtained from analysis of effluents of the Iowa plants.

B. Laboratory Methods and Equipment

The techniques adopted for making long-term BOD studies of the final effluents using the jug dilution method will be discussed first. Verification of the jug dilution techniques using a synthetic sewage will be summarized in the second section. Specific laboratory analyses made of the final effluents from the selected water pollution control plants will be detailed in the third section. The data obtained from these analyses were used subsequently in mathematical evaluation of BOD progression. Both carbonaceous and nitrogenous oxygen demands were of primary interest.

1. The jug dilution method of making long-term BOD studies

The standard BOD bottle dilution method is commonly employed in conducting laboratory analysis of BOD_5 values (Standard Methods, 1965). However, the method presents several disadvantages when long-term studies for periods up to 20 days or more are conducted:

(1) An extraordinary number of individual BOD bottles are involved in just the BOD determinations for the period of the test,

(2) If the waste strength is not known within close tolerances, several different sample dilutions are necessary to avoid depletion of the limited DO concentration available in water,

(3) Separate dilution bottles must be included for all other determinations, including nitrification, COD, bacteria, etc., and

(4) Use of separate dilution bottles subdivides the sample into individual portions, requiring the assumption of homogeneity of sample among all bottles or the use of sufficient replicates to avoid inconsistencies.

The jug dilution method was developed as a simple but adequate technique for conducting long-term studies of the BOD progression of final effluents. Orford et al. (1953) expanded previous efforts to develop the method and presented an improved version which was adopted for use in this study.

The large number of individual dilution bottles are replaced in the jug dilution method with one or more units of two 1-gal jugs operated in series. One of the jugs in the series is the sample jug and the second is the supply jug. Additional units are required for replicates or additional tests. Initially each jug is filled with the desired mixture of effluent and dilution water. In the system developed by Orford et al., the sample jug is stoppered to exclude air, and refilled (by careful siphoning) and restoppered after each laboratory sample is withdrawn for dissolved oxygen or other determinations. The volume of sample withdrawn from the sample jug is replaced from the supply jug and the incubation of both jugs is continued, the supply jug remaining open to the atmosphere. The mixture in the supply jug decreases in volume during a test period as its contents are used to replace the laboratory sample volumes withdrawn from the closed sample jug.

If the dissolved oxygen content of the sample jug nears depletion, the contents of the jug are emptied into a large beaker or cylinder and aerated to increase the DO to near-saturation. The sample jug is refilled, using the mixture in the supply jug to make up any loss in handling. A new initial DO sample is taken and the test is continued. The supply jug may on occasion need to be reaerated also in the first days of a test period, but normally exposure to the atmosphere is sufficient to replenish the DO without mechanical aeration.

Using this technique, all samples are taken from the closed sample jug with the sample volume being replaced from the supply jug. To keep errors in DO concentration to a minimum, since the supply jug DO is not measured, the ratio of the sample volume being withdrawn to the mixture volume contained in the sample jug must be small. The improved technique developed by Orford et al. includes a modified DO determination using 60-ml glass stoppered bottles in place of the usual 300-ml BOD bottles. The standard azide modification of the Winkler DO method (Standard Methods, 1965) is further modified as follows:

(1) 0.2 ml of each of the reagents is used in place of the standard 1 ml, thus providing the same reagent concentration,

(2) 50 ml of the sample is titrated with the thiosulfate instead of the standard volume of 200 ml,

(3) The normality of the sodium thiosulfate used for titration is decreased to 0.00625 from the standard test value of 0.025, which permits the ml used in titration to be the DO level in mg/l.

Several other test procedures and problem areas arise with this method. Care must be exercised in titration of the smaller volume, and the use of a continuing dropping rate after the addition of the starch indicator until the moment of color disappearance is encouraged. Otherwise interference can occur from color return.

Comparisons of the jug dilution method with the standard BOD bottle dilution method were made by Orfcrd et al., and in the DO range 4-9 mg/l the average standard deviation was 0.07 mg/l. Half of this error was attributed to the unmeasured but increased DO level of the supply jug from which make-up of the sample jug is obtained. Since this magnitude of error is similar to the error in the standard DO technique, it was concluded that the jug dilution method was satisfactory for experimental studies of BOD progression.

2. Equipment and laboratory apparatus

The jug dilution method was used in the study of the final effluents from the three types of water pollution control plants. The laboratory apparatus and equipment were modified slightly from that used by Orford et al. to minimize problems encountered in the handling of jugs, in pouring from supply to sample jugs, and in reducing the error which can occur in not correcting for the higher DO levels of the supply jug. The revised and improved equipment is shown schematically in Fig. 37. A short outlet of glass tubing was added to the supply jug near the point where the curved bottom begins. The length of plastic hose between supply jug and sample jug was kept as short as possible, usually about 6 in. A glass siphon tube was placed in the sample jug so that the material being withdrawn came from near the bottom and would not become mixed with the inflowing material from the supply jug. Two points of sampling were included in the equipment installation, one near the outlet of the supply jug and the other at the siphon outlet of the sample jug. Drawn glass tubing for the

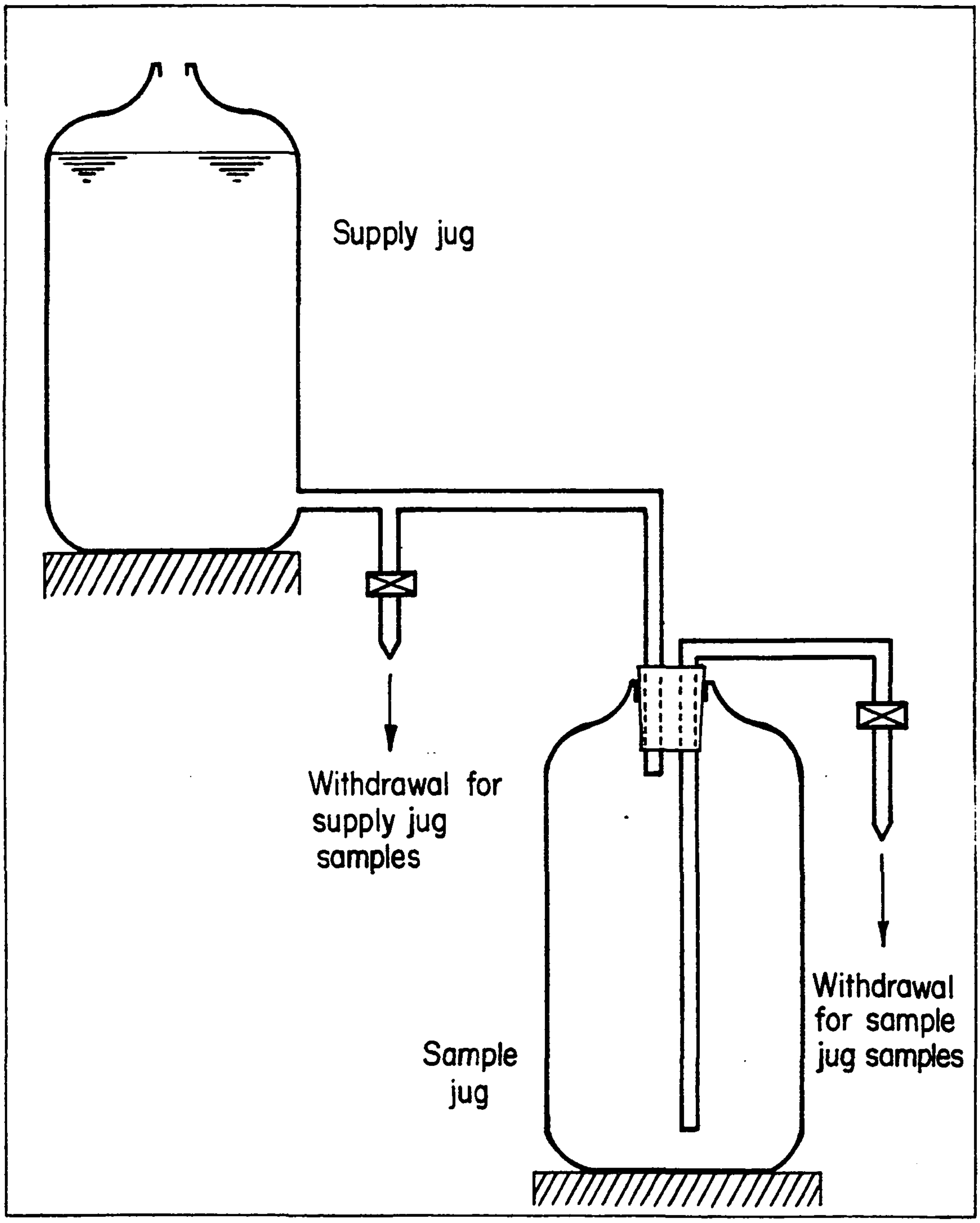

Fig. 37. Schematic diagram of the jug dilution apparatus used for following the BOD progression temporally.

withdrawal outlets permitted the 60 ml titration sample bottles to be filled rapidly but with little or no turbulence or reaeration opportunity. Squeeze clamps were used to close off the plastic outlet tubes just above the tapered outlets.

Five units were constructed and placed in a walk-in incubator in the sanitary engineering laboratories. Temperature regulation in the incubator permitted a 20 deg C level to be maintained, usually within 0.5 deg C. A special stand was constructed that elevated the supply jug above the sample jug, as shown in Fig. 37. Once both units were filled with the sample and the run started, there was no need to open the sample jug to the atmosphere when titration samples were withdrawn. A frame was made for the sample jugs to permit stirring. Commercial magnetic stirrers were placed under each of the five sample jugs, with heavy asbestos sheets and plastic spacers separating the stirrer surface and the jugs. An electric fan was located at the level of the stirrers to dissipate the heat produced by the stirrers. Otherwise, a temperature rise could be detected in a long-term BOD test period. Plastic-coated magnetic bars were placed in the sample jugs so that continuous mixing could be achieved. Because of the open water surface of the supply jugs, it was not considered as imperative to mix their contents. However, they were gently stirred with use of a glass rod twice daily. Since the contents were final effluents, or related seeded dilution water, the amount of suspended or settleable solids was very low and the adopted equipment installation performed satisfactorily.

Additional equipment and laboratory apparatus included large plastic containers for obtaining composite samples of final effluents in the quantities required, and titration apparatus. A volumetric, automatic 10-ml titrating buret was used in all titration work. Reagents were prepared and stored as specified in Standard Methods (1965). Seeded dilution water was prepared and used in the tests when pasteurized samples were included in a test run. Reaeration of the sample and supply jugs, when required, was accomplished by using the compressed air supply available in the laboratory. A small glass tube manifold with drawn glass tube openings of small diameter was constructed to simulate a diffuser mechanism.

Pasteurization of the effluents for the nitrification studies was accomplished using a technique developed by Sawyer and Bradney (1946). The sample was heated rapidly to a temperature of 60 deg C, then cooled in a chilled water bath to 20 deg C. Raw sewage, settled 24 hr, was used for seeding the dilution water when pasteurized samples were included in a test run. One unit was used to determine the BOD of the seeded dilution water, with samples being withdrawn at the same time that the various effluent samples were taken. Raw sewage was obtained at the measuring flume of the Ames water pollution control plant for use as sewage seed.

The steam distillation method was used for determining the components of nitrogen contained in the samples, following digestion of those organic nitrogen samples withdrawn for analysis (Sawyer, 1960; Bremmer, 1965). The steam distillation apparatus was a modification of the semimicro Kjeldahl apparatus (Moore and Diehl, 1962; Bremmer, 1965) used in the sanitary engineering laboratory for research and teaching purposes. Sample sizes of 25-ml volume were used.

3. Test period procedures

Dilution water was prepared initially, with 40 to 60 liters being required for most test periods. Nutrients were added, including the buffer solution. The seed correction unit was placed in operation using about 34 ml of sewage seed per liter in the seed correction jugs. The remainder of the dilution water was then seeded just prior to filling all sample and supply jugs.

The unpasteurized material (synthetic sewage or effluent) was placed in both sample and supply jugs, with the exact volume to be used depending upon the strength of the desired sample. For most of the effluent runs, a 1:9 dilution ratio (a 10% concentration by volume) was used. Each jug was calibrated and numbered to facilitate the filling operation. After the sample volume was placed in the jug, they were filled with seeded dilution water. The connecting tubes and sample point outlets were carefully installed to eliminate all air bubbles from the system. Initial DO and nitrogen samples were then withdrawn from both sample and supply jugs of all units.

The small titration bottles had a capacity of about 64.0 ml to the bottom of the stopper. Titration samples were withdrawn in the following manner. The titration sample from the supply jug was obtained first, following gentle stirring of the contents. The first 35 ml withdrawn were either wasted or incorporated into the nitrogen sample volume. The titration bottle was then filled and stoppered. A similar technique was used in obtaining titration samples next from the sample jug. During one run, triplicate titration samples were withdrawn from the sample jug, requiring the withdrawal of some

250 to 300 ml of sample. Periodic nitrogen determinations required approximately 100 ml of sample. For some of the runs, a portion of the full-strength effluent sample was placed in a separate jug and aerated constantly to determine the gross rate of nitrification. Periodic DO samples were obtained from this jug also to assure sufficient DO levels for nitrification.

The dissolved oxygen in each titration sample bottle was determined using the standard azide modification of the Winkler method modified as noted previously. By determining the DO in both the supply and sample jugs, appropriate corrections could be made for the DO in the sample jugs following the withdrawal of the titration samples. To allow for the displacement of sample when the Winkler test reagents were added, an increased sample size was used; the correction for the addition of 0.4 ml $MnSO_4$ and 0.4 ml of Alkali-Iodide-Azide reagent required that the volume used in final titration be increased to 50.7 ml. Titration of multiple titration samples was laborious, but was possible through the use of the automatic buret and the aid of a laboratory assistant.

Some chemical oxygen demand (COD) tests were run as an added check on the BOD progression. Nitrogen determinations were made at the start of a run and again at the end of the run. Some additional measurements were made periodically during some of the test runs, and, as noted above, nitrogen determinations were made on selected full strength effluent samples. The laboratory techniques for use of the semimicro Kjeldahl method were those used in sanitary engineering teaching and research work at Iowa State University (Bremmer, 1965). This method permits the selective determination of the several components of total nitrogen: ammonia, nitrate, ammonia and nitrate by destroying the nitrite portion first, or determining all three (ammonia, nitrite, and nitrate). Organic nitrogen determination requires an acid digestion prior to distillation. Because the nitrite portion was found subsequently to be difficult to measure accurately with this method, normally the nitrite portion was included in the nitrate fraction. Actually, the greatest portion of the oxygen requirement is involved in the conversion from ammonia to nitrite, and a much smaller requirement for the final conversion to nitrate. Combining the two into a NO_2-NO_3 fraction simplified the analysis and provided adequate indication of the overall conversion from organic and ammonia nitrogen to the more oxidized states. The procedure finally adopted involved using the first 25-ml sample for ammonia determination, then converting the nitrite and nitrate portion of the same sample to ammonia and driving it off for analysis. A second sample was distilled for determining the total of the three forms of nitrogen. A third sample was run for organic nitrogen, using the digestion process.

Once a run was completed and all final determinations were made, the supply and sample jugs were cleaned with a chromic acid cleaning solution and rinsed thoroughly. The plastic tubes and glass siphon and outlet apparatus were placed in a Chlorox solution after a complete wash and rinse cycle.

Daily analysis of the BOD progression was made in the first week of a test run, but frequently 2-day periods were used in the latter part of the test period when the supply jug contents became depleted. At the time the samples were withdrawn for titration, the time was recorded to the nearest 5 min. Additional notes and observations were recorded initially and during the test period.

4. Computational procedures

Data sheets were set up for each unit (supply and sample jug combination), and the necessary corrections were made and entered for the dissolved oxygen content of the sample jug after the withdrawal of all samples for titration or nitrogen determination. For example, if the DO level in the sample jug (3,850 ml) was 6.30 mg/l and that in the supply jug was 6.60, removal of 100 ml from the sample jug left 3,750 ml at 6.30 mg/l and the withdrawn sample was replaced by 100 ml of sample containing 6.60 mg/l DO from the supply jug. The corrected DO level in the sample jug was therefore 6.31. Larger corrections were encountered when the DO level in the sample jug reached 2 to 3 mg/l and the DO level in the supply jug remained high, from 6 to 7 mg/l.

The corrected DO level served as a new initial DO value for the next incremental time period. Subtracting the DO value at the end of this next period from the corrected initial DO level provided the DO depletion for the incremental time period. These DO depletion values then became the basic data for the test period. By subtracting these depletion values successively from the initial DO content, a simulated DO residual curve was obtained. The seed correction curve was also obtained in these initial computations.

A second data sheet was used for listing the final BOD computations. The seed correction was subtracted from the DO depletion value and the result multiplied by the dilution ratio to give the observed BOD value. Duplicate results could then be averaged and the results plotted.

Some benefit was gained also by plotting the DO levels in the supply jugs and the simulated DO residual values of the sample jugs. The supply jug DO levels provided a "spoon-shaped" depletion and recovery curve whereas the DO residual curve continued downward. The faired curves provided a check on the consistency of the experimental results, and the smoothed data were used if an erratic value was encountered.

C. Initial Results Using a Synthetic Sewage

The ability of the jug dilution method to measure the progression of BOD was evaluated in the initial runs. The work of Busch (1958) suggested a means of verifying the operation of the units. Following a brief initial run to check the techniques and procedures, two runs were made using a synthetic sewage mixture consisting of a 1:1 mixture of glucose and glutamic acid mixed with seeded dilution water. The first run was made with an initial synthetic sewage concentration of 15 mg/l and the second of 7.5 mg/l. A unique characteristic of this synthetic sewage is its almost 1:1 correspondence between initial concentration and theoretical oxygen demand. This provides a convenient check of BOD progression.

It was also desired to investigate the effect of stirring of the sample in the sample jug on the BOD progression rates. Therefore, the operational procedure included duplicate units stirred and duplicate units unstirred except for some water movement during the withdrawal of samples. This latter has the effect of mixing, as will be shown subsequently. Triplicate standard dilution bottle samples served as the control, with Busch's results with a Warburg respirometer providing additional comparative data for a mixed or stirred system.

The results of these two runs are summarized in Table 46 and shown in Figs. 38 and 39. Inspection of the plotted results indicates that a plateau effect is achieved with the synthetic sewage, and that the stirred samples most nearly reproduce the work of Busch. The standard BOD dilution bottle control gave results which were either similar to the unstirred samples, or slightly less. The excessive increase in BOD progression of one of the stirred samples in Run No. 3 is attributed to an increase in temperature when the asbestos insulation was dislodged. The initial runs showed also that precise results could not be expected, because of the several corrections that the jug dilution method requires. However, it was concluded that it would be satisfactory for the analysis of final effluents where the total oxygen uptake would reach 50 to 100 mg/l. More sophisticated equipment was not available at this time for refining the experimental program, and the jug dilution method offered a simple means to accomplish the stated purpose.

The results of Run No. 2 were more confirming of Busch's work than were those of Run No. 3 for an additional reason. Triplicate samples were taken for titration in the third run, whereas single samples were obtained in the second. Although it was thought that this would improve the sampling technique, the opposite proved to be true. Because the supply jug has a higher DO level, as each sample is withdrawn the DO

Table 46. Experimental results for a synthetic sewage, Run No. 2 and Run No. 3[a]

Hour	Stirred dilution jug units: Jug No. 1, BOD, mg/l	Stirred dilution jug units: Jug No. 3, BOD, mg/l	Stirred dilution jug units: Average BOD, mg/l	Hour	Unstirred dilution jug units: Jug No. 5, BOD, mg/l	Unstirred dilution jug units: Jug No. 7, BOD, mg/l	Unstirred dilution jug units: Average BOD, mg/l	Standard BOD dilution bottle control: Hour	Standard BOD dilution bottle control: BOD, mg/l
Run No. 2									
0	0	0	0	0	0	0	0	0	0
17.5	5.29	6.00	5.64	17.7	5.25	5.37	5.71	17.0	3.98
23.0	5.57	6.15	5.86	23.2	5.28	5.66	5.47	22.5	4.74
37.5	6.32	6.70	6.51	37.7	6.22	6.04	6.13	36.0	5.39
69.0	7.23	7.06	7.15	69.5	6.98	6.33	6.60	67.5	5.87
92.5	9.46	9.51	9.48	93.0	8.70	7.66	8.18	90.0	8.84
123.	11.22	11.17	11.20	123.5	10.82	9.79	10.30	122.	10.08
141.	11.59	11.47	11.53	141.5	11.21	9.99	10.60	139.5	10.64
186.	12.50	12.50	12.50	186.5	12.24	10.72	11.48		
Run No. 3									
0	0	0	0	0	0	0	0	0	0
15.0	1.29	1.14	1.22	16.5	1.18	0.92	1.05	15.0	0.71
27.0	3.21	3.01	3.11	29.5	2.88	2.82	2.85	27.0	3.15
52.5	3.14	3.08	3.11	53.5	2.87	2.83	2.85	52.5	3.19
74.0	3.55	3.61	3.58	75.0	3.42	3.80	3.61	74.0	3.63
96.0	4.79	5.10	4.94	96.5	4.51	4.39	4.45	96.0	4.61
121.5	5.36	5.98	5.67	123.	4.90	4.70	4.80	121.5	4.93
168.	5.93	6.92	6.42	168.5	5.38	5.09	5.24	168.0	5.28

[a]A mixture of 50% glucose, 50% glutamic acid in solution, with a concentration of 15 mg/l in Run No. 2 and 7.5 mg/l in Run No. 3.

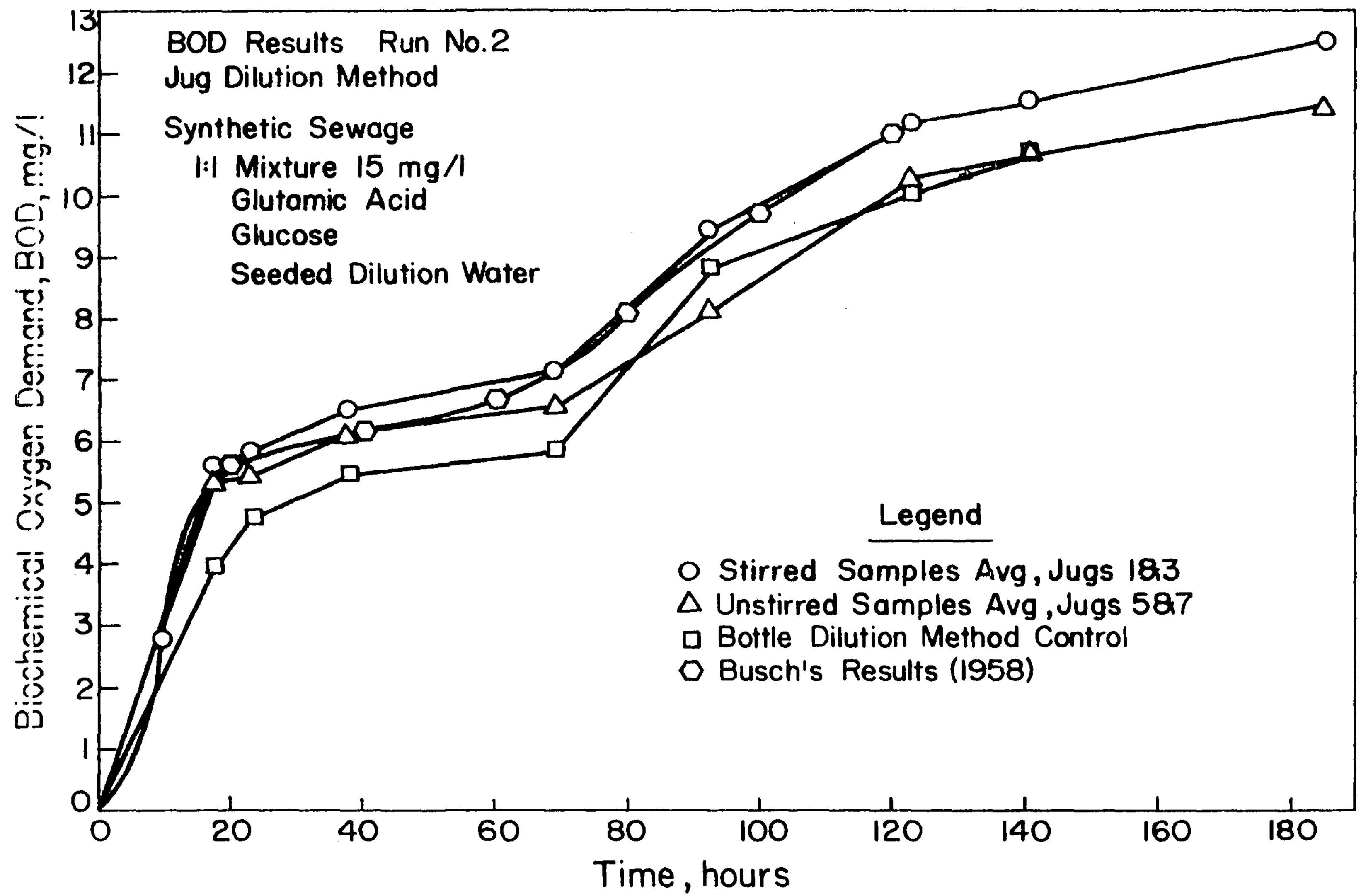

Fig. 38. BOD progression using a synthetic sewage, Run No. 2.

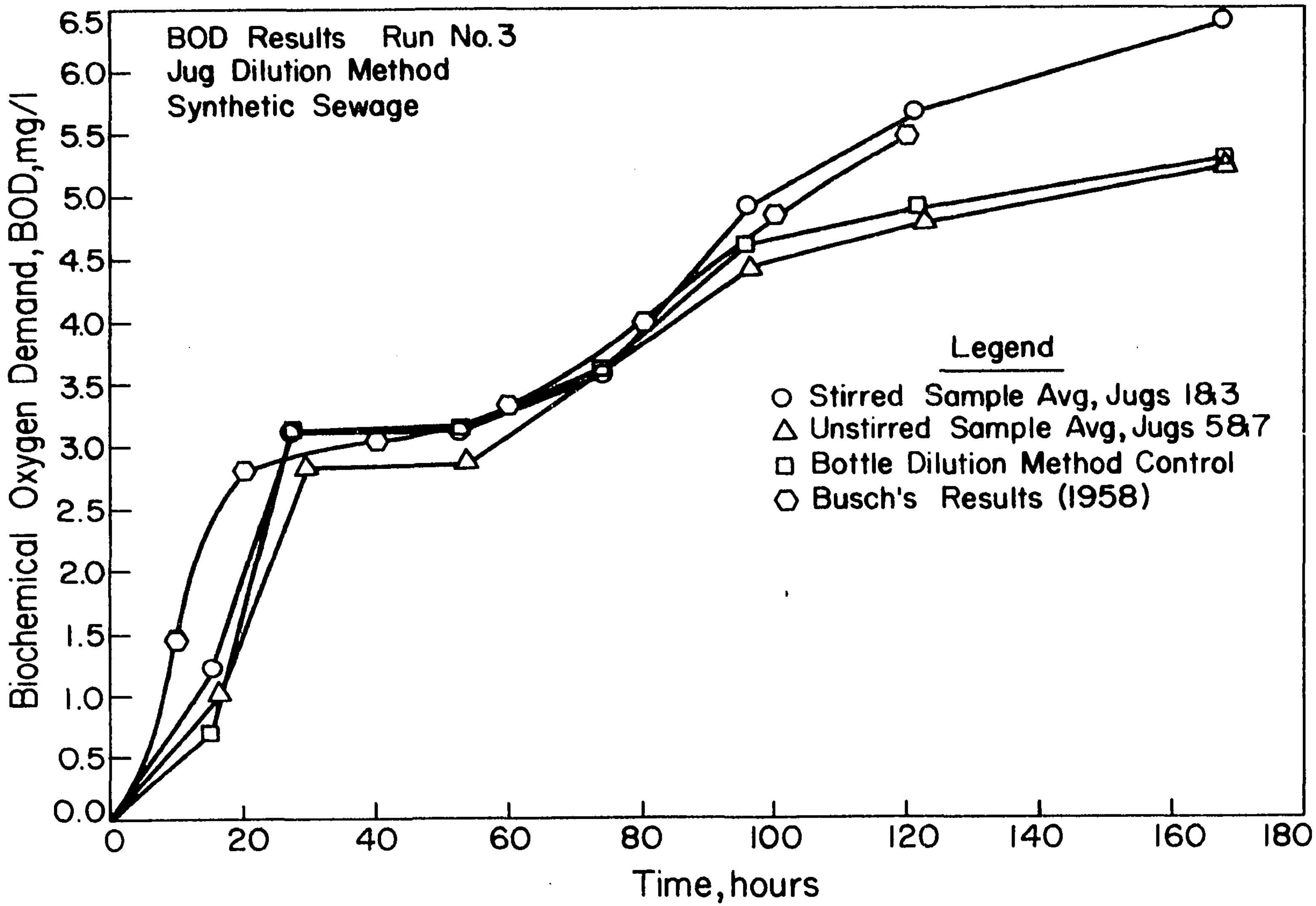

Fig. 39. BOD progression using a synthetic sewage, Run No. 3.

content of the sample jug is changing. For example, the triplicate samples might give successive results such as 2.55, 2.67, and 2.82 mg/l, with an average of 2.68. This increasing trend in successive samples occurred even when stirring was stopped for several minutes prior to withdrawing a titration sample. Therefore, the technique of obtaining triplicate samples was abandoned and only one sample per day was withdrawn thereafter.

A value of about 40% of the theoretical BOD is reached for the synthetic sewage in the first day of the test period, agreeing with Busch's results. The definite trend of the BOD progression for a simple synthetic sewage, representing simple compounds, confirms the doubts of Busch of the applicability of the first-order reaction for BOD progression for a very specific material. Only the heterogeneity of a domestic or combined domestic and industrial waste and a multiplicity of the organisms involved in the BOD and related food chain can overshadow the singularity of the plateau achieved in simple substrates. This concept was illustrated by Busch for a domestic sewage that clearly behaves much differently in BOD progression than do the simpler compounds.

These two tests were run for 7-day periods, the maximum length for which the supply jugs could support the units. One reaeration was required for Run No. 2, but none for Run No. 3 in which the original DO level was sufficient for the 7.5 mg/l theoretical oxygen demand. Busch found that about 73% of the theoretical oxygen demand was exerted in a 5-day period. The results using the stirred samples confirmed this demand and showed further that about 80 to 83% of the theoretical oxygen demand was required for biochemical reactions in the 7-day period. The plateau value of BOD is about 40% of the theoretical oxygen demand in both runs.

The BOD dilution bottle control in Run No. 2 was consistently lower in BOD progression than the jug dilution results, except in the later stages of the run. It then followed the BOD progression of the unstirred samples. In the third run, the BOD dilution bottle control results were as high as the mixed sample jug values in the first 3 days of the run, then drifted lower to match the unmixed sample results again. There was no apparent reason for the differences noted.

It was concluded that the jug dilution method produced satisfactory results for long-term BOD analyses and could be used in the study of the characteristics of final effluents. However, care must be exercised in operating the jug dilution units to prevent temperature rises in the stirred units, as heat is transmitted from the electric stirring units to the surrounding environment. In addition, the use of duplicate units assisted in providing comparative checks on the progression of BOD between units.

D. Experimental Studies of Effluents from Treatment Units

Following the initial operational runs with the jug dilution units, the experimental investigation of the final effluents obtained from three types of treatment processes was conducted. In addition to the analysis of BOD progression of the effluent samples, studies of pasteurized samples and of nitrogen levels were included in selected runs.

1. Characteristics of the effluents from the Ames trickling filter plant

Three long-term studies were conducted using effluent samples obtained at the discharge weir of the final clarifier at the Ames water pollution control plant. In Run No. 4, the first of the effluent series, additional observation of the effect of stirring was made. Standard BOD dilution bottle control samples were also included in the investigation. In the second of this series, Run No. 5, pasteurization of one part of the sample was included in the test. The effect of nitrification was also studied. Run No. 6 was similar to the previous run but additional nitrification analysis was made of a full-strength sample of the final effluent. Results of the three are reported and discussed in this section.

a. Results of the first test period, Run No. 4 This run was made for a period of 7 days. The dilution ratio was 1:8, and based on the work of Busch (1958), the dilution water was seeded with 5 ml/l of settled raw sewage (24 hr). No reaeration was required during the test period. Triplicate samples of the BOD bottle dilution control were analyzed each day during the run.

The results of Run No. 4 are listed in Table 47 and plotted in Fig. 40. The data indicate that reasonable results can be obtained using the jug dilution method, if the many factors involved in biological processes are considered. A 15 to 20% increase in BOD is observed for the stirred sample units, with the unstirred sample results coinciding closely with the BOD dilution bottle control values. The average 5-day BOD is 56 to 57 mg/l for the late winter sample, as determined with the

Table 47. Experimental results for a trickling filter effluent, Run No. 4[a]

Hour	Stirred dilution jug units: Jug No. 1, BOD, mg/l	Stirred dilution jug units: Jug No. 3, BOD, mg/l	Stirred dilution jug units: Average BOD, mg/l	Hour	Unstirred dilution jug units: Jug No. 5, BOD, mg/l	Unstirred dilution jug units: Jug No. 7, BOD, mg/l	Unstirred dilution jug units: Average BOD, mg/l	Standard BOD dilution bottle control: Hour	Standard BOD dilution bottle control: BOD, mg/l
0	0	0	0	0	0	0	0	0	0
13.5	13.95	11.97	12.96	14.0	12.78	13.14	12.96	15.0	10.17
24.0	17.10	17.82	17.46	24.5	14.67	15.66	15.16	25.0	11.97
41.5	27.63	26.82	27.22	42.0	24.12	23.76	23.94	42.5	23.22
71.5	40.50	38.16	39.33	72.0	34.11	33.84	33.97	72.5	34.47
96.5	47.97	45.36	46.67	97.0	37.98	40.41	40.19	97.5	39.78
120.5	58.23	54.27	56.25	121.0	44.82	46.80	45.81	121.5	47.97
144.0	66.78	62.91	64.84	144.5	51.21	51.93	51.57	145.0	55.17
167.5	75.60	71.46	73.53	168.0	56.61	58.23	57.42	168.5	61.83

[a]A 24-hr composite from the Ames water pollution control plant, 1 qt per mgd every 2 hr, February 2-3, 1966.

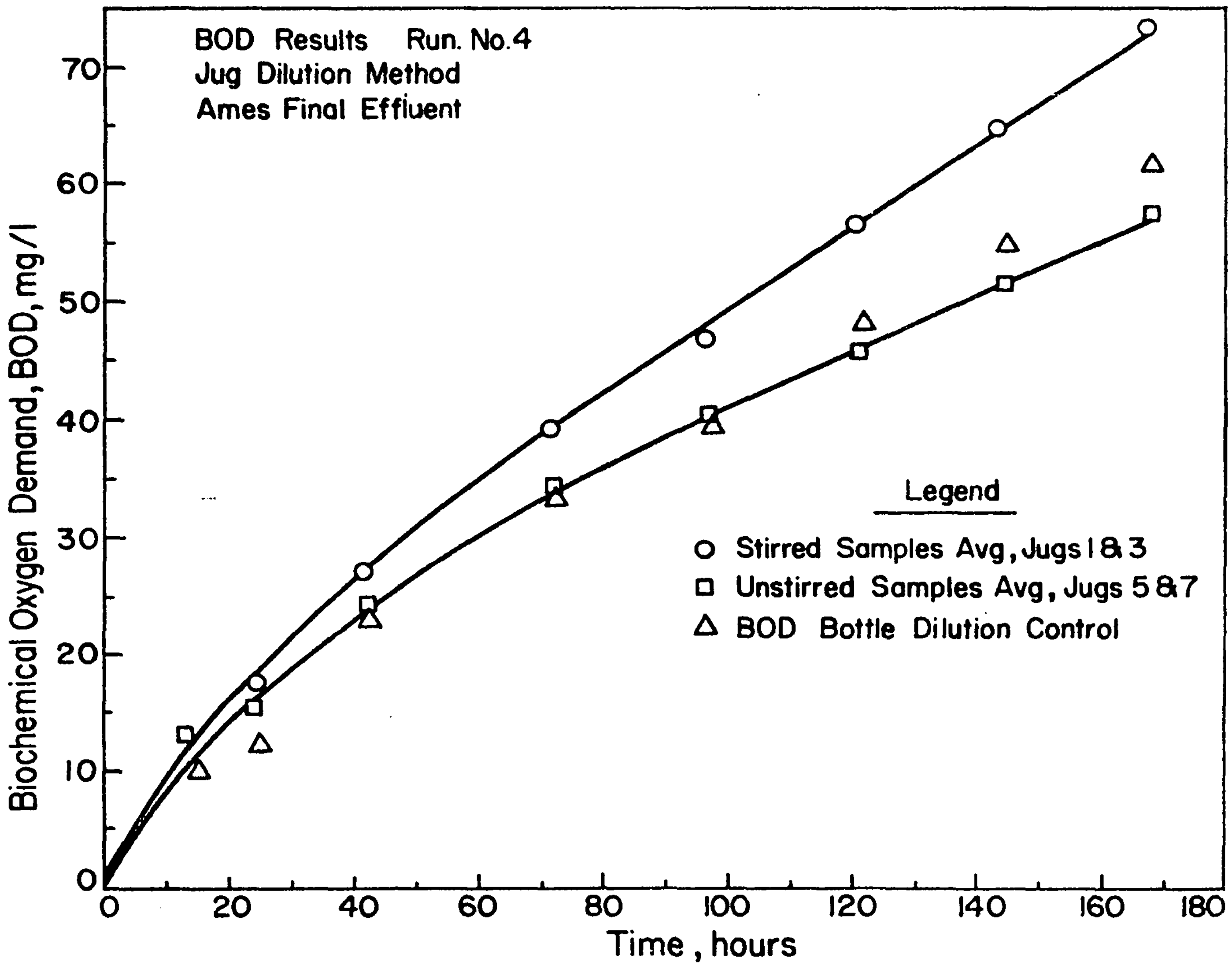

Fig. 40. BOD progression for a trickling filter effluent, Ames water pollution control plant, Run No. 4.

stirred samples. Plant operation data of the Ames water pollution control plant indicate a raw sewage BOD of 180 mg/l and a final effluent BOD of 58 mg/l as determined by the BOD bottle dilution method for the date on which the 24-hr composite was obtained, February 2, 1966. The volume of waste water recorded for this date was 3.4 mgd. These data show that the plant efficiency was about 68 to 70% in terms of overall BOD removal.

The slope of the BOD curves at the end of the test are fairly steep, indicating a high ultimate value and probable effect of nitrification. Therefore, it was determined that the next run should include pasteurization permitting the carbonaceous demand to be separated from the total oxygen demand.

b. <u>Results of the second test period, Run No. 5</u> A second 24-hr composite sample of final effluent was obtained from the Ames water pollution control plant. One qt per mgd of flow was withdrawn every 2 hr at the final clarifier discharge weir. An additional jug dilution unit was installed permitting stirred, unstirred, and pasteurized samples to be analyzed. A dilution ratio of 1:9 was used, with the seeded dilution water containing 2 ml/l of settled raw sewage (24 hr). Triplicate titration samples were withdrawn from the sample jugs for each DO determination. No reaeration was needed for the first 6 days, but the supply jugs were largely depleted of oxygen. At the end of the 6-day test period, the nonpasteurized sample volume in all jugs was mixed and reaerated. The volume was then placed in the unstirred units and operation continued to the 19th day. The pasteurized dilution unit was also operated for the 19-day period.

The initial COD of the effluent was 128 mg/l. Nitrogen determinations for ammonia and total nitrogen were made initially, after 5 days and at the end of the test period. No organic nitrogen determinations were made during the run. Plant operation data for this date indicated a raw sewage BOD_5 of 203 mg/l and a final effluent BOD_5 of 56 mg/I. The initial COD of the raw sewage was reported as 406 mg/l, and the average daily flow was 3.3 mgd.

The BOD results for this sample are listed in Table 48 and plotted in Fig. 41. The nitrogen determinations are shown in Table 49. The difference between the stirred and unstirred sample results remains at about 10% or more. The BOD dilution bottle control remains below the unstirred samples, but the 5-day BOD value of 58 to 59 mg/l compares closely with the value obtained at the treatment plant. Therefore, it can be concluded that good mixing is achieved in the jug dilution method as samples are withdrawn, and unless the material contains a great amount of settleable solids there may not be a need for stirring the sample jug with a magnetic stirrer. Some of the difference between the stirred and unstirred sample results is believed to be due to the warmer temperature environment created by the stirrer apparatus.

Reaeration presents a problem in the jug dilution method, as evidenced by the data shown in Fig. 41. Following reaeration at the 6th day, a rapid increase in BOD progression is noted. Inspection of the laboratory data sheets indicates that the DO levels at the 6th day were severely depleted, being less than 1 mg/l in the stirred samples. Therefore, most of the rapid increase may be due to the elimination of nitrification suppression by low DO levels.

Table 48. Experimental results for a trickling filter effluent; Run No. 5[a]

Days	Stirred dilution jug units Jug No. 1, BOD, mg/l	Jug No. 3, BOD, mg/l	Average BOD, mg/l	Days	Unstirred dilution jug units Jug No. 5, BOD, mg/l	Jug No. 7, BOD, mg/l	Average BOD, mg/l	Days	Unstirred pasteurized unit Jug No. 11, BOD, mg/l
0	0	0	0	0	0	0	0	0	0
0.79	23.2	22.6	22.9	0.81	20.7	22.9	21.8	0.81	10.8
1.83	38.7	33.1	35.9	1.85	34.0	33.7	33.8	1.85	16.7
2.83	51.7	44.8	48.3	2.85	47.0	49.0	48.0	2.85	27.9
4.00	73.0	60.4	66.7	4.02	57.2	62.1	59.7	4.02	35.0
4.89	76.8	68.3	72.6	4.90	67.1	71.8	69.5	4.90	38.4
6.02	90.8	86.1	88.4	6.04	77.2	81.8	79.5	6.04	41.4
				7.80	79.3	109.7	94.5	7.80	53.4
				9.60	125.9	142.9	134.4	9.60	58.4
				11.80	136.	158.	147.	11.80	64.6
				12.90	157.	169.	163.	12.90	73.9
				14.73	165.	186.	176.	14.73	79.4
				16.68	176.	198.	187.	16.68	91.8
				18.71	183.	205.	194.	18.71	105.

[a]A 24-hr composite from the Ames water pollution control plant, 1 qt per mgd every 2 hr, February 21-22, 1966; the BOD dilution bottle control values for the 6 days in column 1 were 19.3, 30.5, 40.1, 49.4, 58.5, and 73.5 respectively, in mg/l.

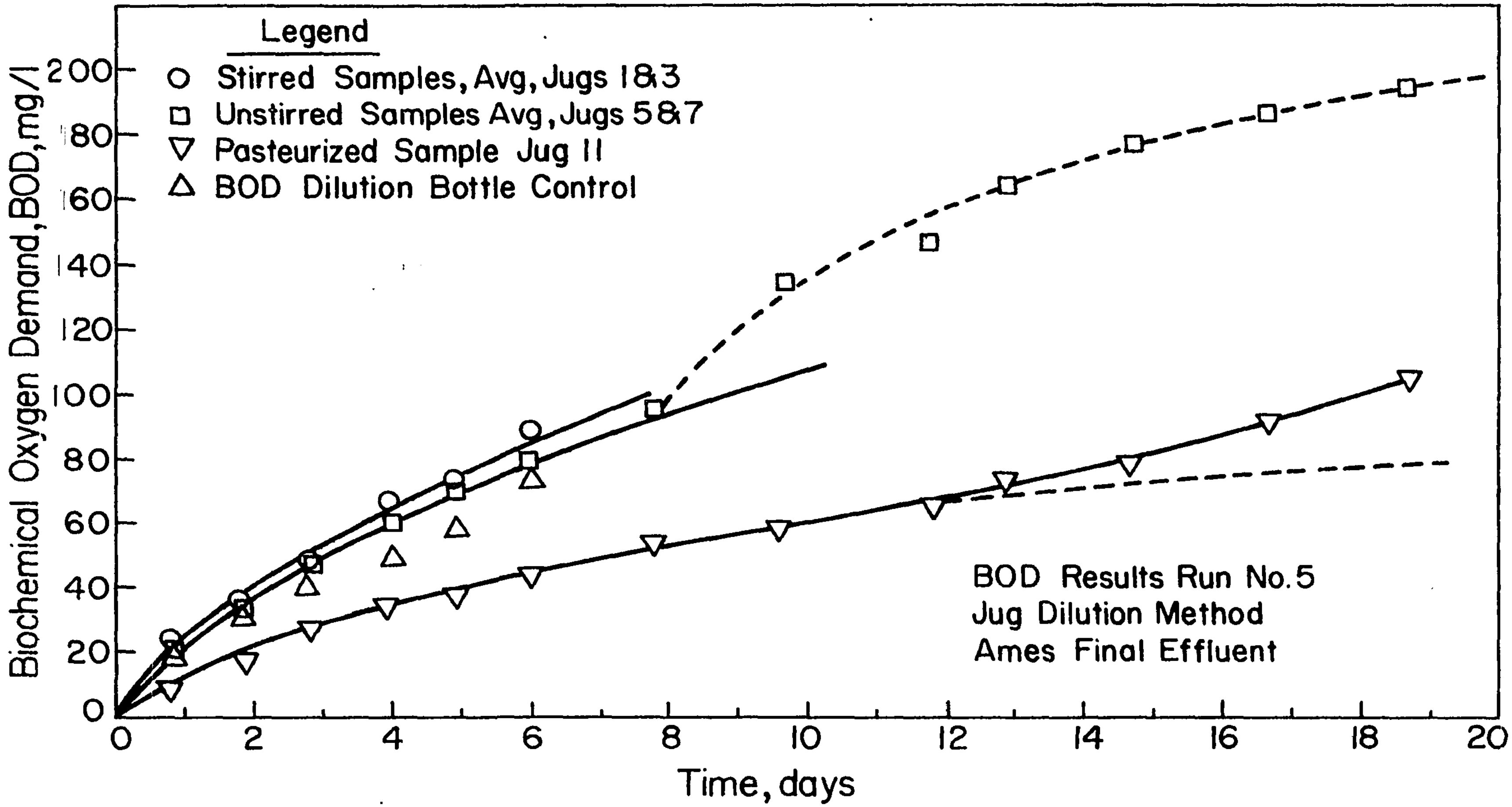

Fig. 41. BOD progression for a trickling filter effluent, Ames water pollution control plant, Run No. 5.

Table 49. Nitrogen levels and total nitrogen balance, Run No. 5[a]

Day	Sample jug	Ammonia, mg/l - N	Nitrite and nitrate, mg/l - N	Organic nitrogen,[b] mg/l - N	Total nitrogen, mg/l - N
0	All jugs, composite sample	15.3	3.9	3.6[b]	22.8[b]
5	Unstirred samples, Jugs 5 and 7	14.7	7.3	0.8[b]	22.8[b]
19	Unstirred samples, Jugs 5 and 7	1.0	21.8	0.0[b]	22.8
19	Pasteurized sample, Jug 11	13.2	8.9	0.7[b]	22.8[b]

[a]Ames water pollution control plant, final effluent, February 21-22, 1966.

[b]Values of organic nitrogen determined by subtraction, assuming that the organic nitrogen content was zero at the 19th day in the unstirred samples, and the observed 22.8 mg/l N-nitrogen was the total for all days.

The results show the tremendous BOD difference experienced using pasteurized and unpasteurized samples. For the first 10 days, the BOD progression of the pasteurized sample was about 60% of the nonpasteurized results. The improvement in plant efficiency can be illustrated with these results. For the plant data of 203 mg/l raw sewage BOD_5 and an unpasteurized effluent BOD_5 of from 56 to 58 mg/l, the plant efficiency is computed to be 71 to 72%. If plant efficiency is based on the pasteurized (carbonaceous) effluent BOD_5 of 40 mg/l, the plant efficiency is 80%. Inspection of Fig. 41 indicates that the effluent is in an active state of nitrification. This is also confirmed by the data listed in Table 49 which show that some nitrification has taken place in the filters, since the nitrogen content of the incoming raw sewage normally has all been in the form of ammonia (with some organic nitrogen).

The nitrogen data provide some explanation for the BOD requirements shown in Fig. 41. For the pasteurized sample, a total of 5.0 mg/l N-nitrogen was converted from organic and ammonia nitrogen to the nitrate form, requiring a theoretical oxygen requirement of about 23 mg/l. Inspection of Fig. 41 indicates a difference of about 25 to 26 mg/l BOD at the 19th day between the observed BOD curve for the pasteurized sample and the assumed ultimate BOD value of about 80 mg/l. For the unstirred samples, a total of 17.9 mg/l of ammonia and assumed organic nitrogen was converted, requiring about 82 mg/l of oxygen. The unstirred sample BOD curve is higher than this above the pasteurized sample BOD curve, indicating that the overall balance is not precisely accounted for. However, the effect of nitrification is clearly evident.

c. <u>Results of the third test period, Run No. 6</u> One additional investigation was made of the Ames final effluent to permit further analysis of the effect of pasteurization and related nitrification problems. Two of the jug dilution units were used for pasteurized samples, two for normal effluent samples, and one for seed correction. A dilution ratio of 1:9 was maintained to provide some comparison with previous results. Other laboratory techniques remained the same as for Run No. 5.

The waste water flow at the plant was 4.1 mgd and the BOD_5 of raw sewage influent and the final effluent were recorded as 144 mg/l and 47 mg/l, respectively. This gave a plant BOD removal efficiency of 67%.

The final effluent sample was obtained during the period from noon on March 29, 1966 to noon on March 30, 1966.

The initial COD of the final effluent was 105 mg/l. Another aerated sample of the full-strength final effluent was analyzed after 5 days and found to have a COD of 30 mg/l. Nitrogen determinations were made of both raw sewage and final effluent samples. One sample of the full-strength effluent was aerated continuously, and nitrogen determinations were made of this sample as well as for the pasteurized and unpasteurized samples. The length of the test period was 20 days.

The results for Run No. 6 are listed in Table 50 and are plotted in Fig. 42. Again, reaeration presented a problem, as evidenced by the rapid increase in BOD progression following reaeration at the 8th day. The effect is considered to be related to reaeration since active nitrification was in progress at the beginning of the test period. Because the DO levels in the unpasteurized dilution jugs were below 2 mg/l for the 6th to the 8th days, the increase may be attributed somewhat to the recovery of nitrification following reaeration. The nitrification of the pasteurized samples after the 8th or 10th day is evident in Fig. 42, and the difference between the carbonaceous curve extended and the observed curve agrees within reason with the oxygen consumed in the nitrifying process.

The results indicate that there is little use in continuing BOD tests beyond the 10th day for carbonaceous BOD analysis unless close observation and measurement is made of the nitrification requirement. Only if the latter is measured can the carbonaceous BOD curve be extrapolated. Of greater importance is the observation that BOD tests of

Table 50. Experimental results for a trickling filter effluent, Run No. 6[a]

Day	Final effluent sample Jug No. 1, BOD, mg/l	Jug No. 3, BOD, mg/l	Average BOD, mg/l	Pasteurized final effluent sample Jug No. 5, BOD, mg/l	Jug No. 9, BOD, mg/l	Average BOD, mg/l
0	0	0	0	0	0	0
1	12.5	14.9	13.7	11.3	10.0	10.6
2	22.5	25.4	24.0	18.0	16.3	17.2
3	31.5	34.6	33.0	23.2	21.2	22.2
4	40.7	42.7	41.7	27.5	25.2	26.4
5	48.3	50.2	49.2	31.4	28.8	30.1
6	55.6	57.2	56.4	35.0	32.1	33.6
7	61.2	63.4	62.3	38.3	35.1	36.7
8	68.7	69.2	69.0	41.7	38.1	39.9
9	82.0	82.1	82.0	45.6	42.7	44.2
10	91.7	90.9	91.3	49.8	47.1	48.4
12	104.3	104.0	104.2	57.3	54.4	55.8
14	113.2	113.2	113.2	64.4	60.8	62.6
16	121.0	121.3	121.2	71.6	66.9	69.2
18	127.7	128.2	128.0	80.6	76.9	78.8
20	134.0	134.6	134.3	92.9	97.6	95.3

[a]A 24-hr composite from the Ames water pollution control plant, 1/2 qt per mgd every 2 hr, March 29-30, 1966; values computed from faired depletion curves for each dilution jug unit.

unpasteurized samples can easily give erratic results, since the BOD progression may be suppressed at low DO levels. The nitrogen balance values are listed in Table 51, and again illustrate the large oxygen requirement for oxidation of the ammonia and organic nitrogen. For the test run, the 14 mg/l of N-nitrogen in these two components would require 64 mg/l of oxygen theoretically, or more than either the BOD_5 or the ultimate BOD of the carbonaceous portion of the final effluent. The importance of the nitrification role in waste treatment must be emphasized. The plant efficiency increases from 67 to almost 80% if it is based on carbonaceous BOD.

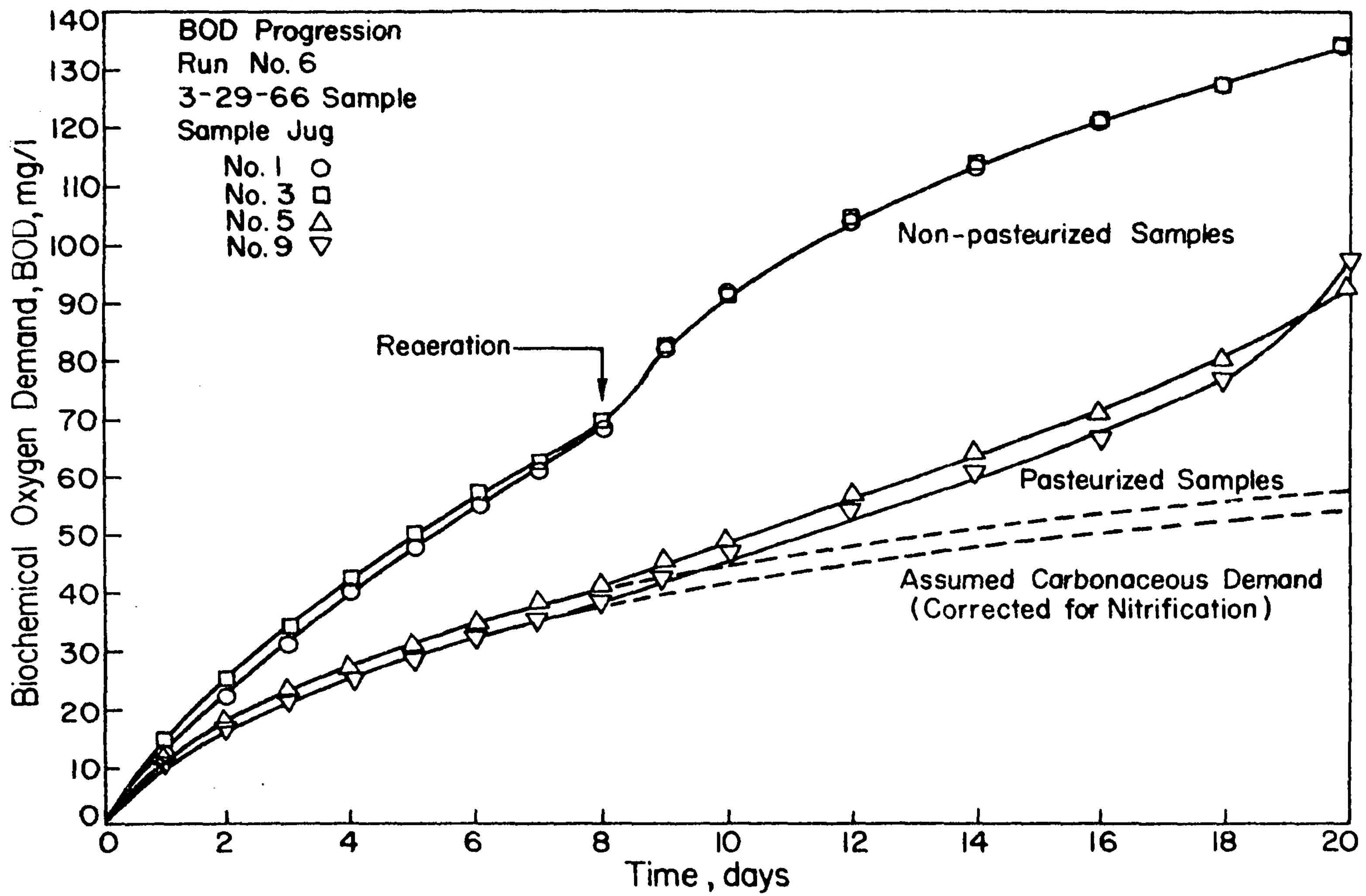

Fig. 42. BOD progression for a trickling filter effluent, Ames water pollution control plant, Run No. 6.

Table 51. Nitrogen balances in a domestic sewage at Ames, Iowa[a]

Component of sewage	Laboratory treatment	Date of analysis	Days from start or run	Amount of N-nitrogen measured, mg/l: Organic nitrogen	Ammonia nitrogen	Nitrites and nitrates	Total nitrogen
Final effluent, 24-hr composite, March 29-30, 1966	Aerated continuously	3-30-66	0	5.0	9.0	6.2	20.2
		4-4-66	5	4.8	6.6	8.4	19.8
		4-7-66	8	3.9	0	15.2	20.1
		4-19-66	20	2.7	0	18.0	20.7
Final effluent, 24-hr composite, March 29-30, 1966	Nonpasteurized dilution jugs	3-30-66	0	5.0	9.0	6.2	20.2
		4-7-66	8	—	4.5	14.0	—
		4-19-66	20	—	0	16.8	—
Final effluent, 24-hr composite, March 29-30, 1966	Pasteurized dilution jugs	3-30-66	0	5.0	9.0	6.2	20.2
		4-7-66	8	—	12.0	6.2	—
		4-19-66	20	—	8.0	12.0	—
Raw sewage	Grab sample	3-31-66	0	11.6	16.8	0	28.4
Final effluent	Grab sample	3-31-66	0	4.5	12.1	5.7	22.3

[a]Analysis made during Run No. 6 of BOD progression study.

Table 51. Cont.

Component of sewage	Laboratory treatment	Date of analysis	Days from start or run	Amount of N-nitrogen measured, mg/l Organic nitrogen	Ammonia nitrogen	Nitrites and nitrates	Total nitrogen
Raw sewage	Grab sample	4-14-66	0	11.0	20.2	0	31.2
Final effluent	Grab sample	4-14-66	0	5.8	13.5	7.3	26.6

The nitrogen balance data of Table 51 show that increased nitrification is achieved in the trickling filter plant as the weather warms in the spring. The mean daily temperature increased from 12 deg F to 45 deg F during the month between Runs 5 and 6. A semblance of the nitrogen balance through the plant is illustrated in Table 51. The total nitrogen level was 28 to 30 mg/l N-nitrogen, in the influent raw sewage, and 22 to 27 mg/l in the final effluent for the two grab samples. Slightly less, about 20 to 21 mg/l were observed in the final effluent sample used in Run No. 6. Most of the ammonia was oxidized to the nitrate state by the end of the 8th day.

2. <u>Characteristics of the effluent from the Marshalltown activated sludge plant</u>

The activated sludge process of secondary sewage treatment is noted for its high efficiency under ideal operating conditions, producing a "polished" effluent of high clarity. The only conventional activated sludge plant in Iowa is located at Marshalltown, located about 35 mi due east of Ames. Because of its close proximity, it was convenient to include it in the effluent analysis program. One sample was composited over a 24-hr period on June 7-8, 1966 using the 1 qt per mgd per 2-hr sampling period technique. The plant operation data indicate a raw sewage BOD_5 of about 200 to 210 mg/l, a waste flow of 5.3 mgd and an estimated population equivalent of 50,000 to 55,000. One large packing plant is served by the water pollution control plant, and the overall industrial waste load is high. Dry weather waste water flows have a BOD_5 of from 350 to 375 mg/l (City of Marshalltown, 1968).

The COD of the final effluent was 55 mg/l. The test period for BOD progression was 16 days, and nitrogen determinations were made periodically. Only one dilution jug unit was used for each analysis, using normal and pasteurized samples.

The results of the BOD progression are included in Table 52 and plotted in Fig. 43. The nitrogen balance results are listed in Table 44. The trends shown in Fig. 43 illustrate that nitrification completely dominates the BOD progression in this effluent (which contains a large amount of ammonia and organic nitrogen). Complete nitrification would require over 100 mg/l of DO as compared to the estimated ultimate carbonaceous and BOD of about 10 mg/l, as shown in Fig. 43. Again, the difference between carbonaceous and nitrification oxygen demands, as computed from the data in Table 53, explains the differences observed in Fig. 43. The plant efficiency is about 96% for the carbonaceous load, but drops to 93% for the total BOD indicated in Fig. 43, at the 5-day point in the test period. Based on the ultimate carbonaceous BOD of 10 mg/l, the plant efficiency is higher than that experienced with the trickling filter plant at Ames. The ability of the activated sludge process to reduce the carbonaceous BOD of the waste load to a very low value is evident from the results of this investigation.

The nitrogen balance studies were not so conclusive in this run, as shown in Table 53. The levels of organic nitrogen were too low to be determined accurately, especially in the diluted samples. However, the suppression of nitrification by pasteurization is clearly evident and if the conversion of organic nitrogen is neglected, the conversion of ammonia to nitrates is fairly well balanced.

Table 52. Experimental results for an activated sludge effluent, Run No. 7[a]

Day	Untreated final effluent sample Dilution jug No. 1 BOD, mg/l	Pasteurized final effluent sample Dilution jug No. 3 BOD, mg/l
0	0	0
0.92	3.5	1.8
1.94	5.6	3.4
2.94	8.1	4.4
3.89	10.1	5.6
4.94	12.3	6.5
5.92	16.7	8.7
6.94	23.0	11.7
7.99	34.8	13.4
8.95	37.8	14.0
10.20	43.1	15.4
11.92	52.6	18.0
13.95	58.7	22.3
16.0	62.2	32.5

[a]A 24-hr composite from the Marshalltown water pollution control plant, 1 qt per mgd every 2 hr; dilution of 1:1, reaeration required on 5th, 7th, 9th, 10th, and 12th days.

3. Characteristics of the effluent from the Jewell waste stabilization pond

The treatment process in common use by many smaller communities in the region (including the upper Skunk River basin) is the waste stabilization pond. Both Roland and Jewell have stabilization ponds, and Ellsworth has recently installed a series of anaerobic-aerobic lagoons. A sample of the effluent from the Jewell stabilization pond was obtained at the outfall weir. The sample jug dilution used was 1:1, and other laboratory techniques remained as before. The COD of the effluent was 135 mg/l. The sample contained a substantial amount of algae, but this was not removed.

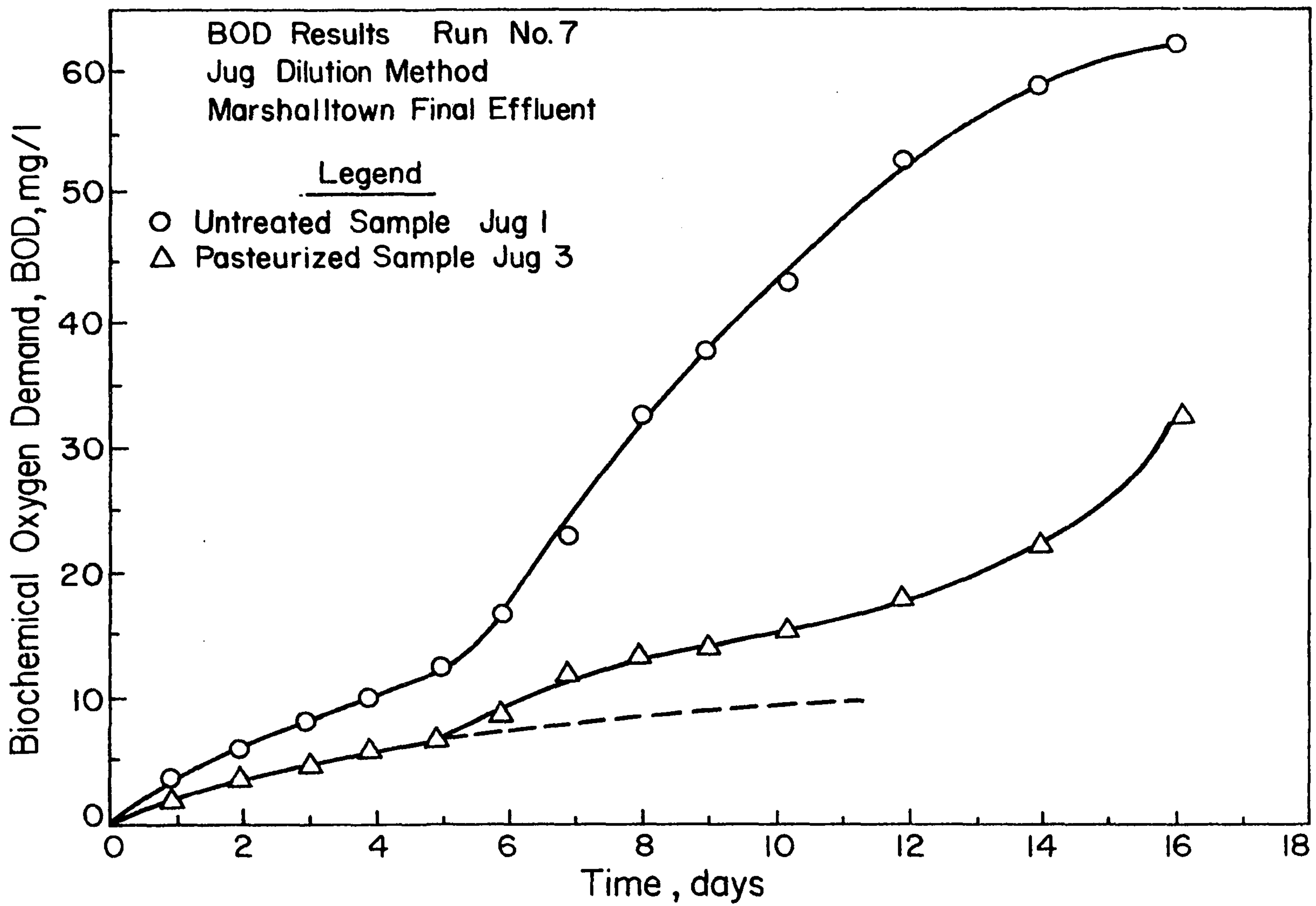

Fig. 43. BOD progression for an activated sludge effluent, Marshalltown water pollution control plant, Run No. 7.

Table 53. The nitrogen balance in the activated sludge plant effluent at Marshalltown, Iowa[a]

Component of sewage	Laboratory treatment	Date of analysis	Days from start of run	Amount of N-nitrogen measured, mg/1 Organic nitrogen	Ammonia nitrogen	Nitrites and nitrates	Total nitrogen
Final effluent 24-hr composite, June 7-8, 1966	Aerated continuously	6-8-66	0	8.3	15.4	0.3	24.0
		6-11-66	3	—	11.8	1.2	—
		6-14-66	6	—	2.3	9.7	—
		6-16-66	8	—	0.3	12.3	—
		6-24-66	16	—	0.6	13.5	—
Final effluent 24-hr composite, June 7-8, 1966	Untreated sample	6-8-66	0	8.3	15.4	0.3	24.0
		6-16-66	8	—	13.2	1.2	—
		6-24-66	16	—	1.4	13.6	—
Final effluent 24-hr composite, June 7-8, 1966	Pasteurized sample	6-8-66	0	8.3	15.4	0.3	24.0
		6-16-66	8	—	6.4	7.2	—
		6-24-66	16	—	7.4	7.6	—

[a]Analysis made during Run No. 7 of BOD progression study.

The BOD results are listed in Table 54 and plotted in Fig. 44. The data indicate that the pasteurized and untreated samples had much the same BOD progression during the first 6 days of the test period. Following the reaeration period at the 6th day, the BOD of the unpasteurized final effluent increased rapidly. The nitrogen determinations indicated 3.1 mg/l organic N-nitrogen, 0.5 mg/l or less ammonia nitrogen, and about 1.0 mg/l nitrites and nitrates. There was no measurable difference during the run because of the low values and the difficulty of measuring low amounts of nitrogen (Sawyer, 1960). Because rainfall had been heavy during the week prior to sampling, some dilution of the contents may have occurred. However, the results show that the effluent carbonaceous BOD is comparable to the carbonaceous BOD of the Ames plant, and much higher than the BOD of the Marshalltown activated sludge process.

Table 54. Experimental results for the Jewell waste stabilization pond effluent, Run No. 8[a]

Day	Final effluent sample Dilution jug No. 5 BOD, mg/l	Pasteurized final effluent sample Dilution jug No. 9 BOD, mg/l
0	0	0
0.96	9.2	6.7
1.92	14.4	12.3
2.96	19.8	18.0
3.92	23.9	21.1
4.96	27.3	24.7
5.96	30.9	27.3
6.92	36.2	28.8
8.17	39.8	31.2
9.94	45.3	34.8
11.94	48.9	38.3
13.88	56.8	42.6

[a]Sample obtained at the outfall weir near the center of the waste stabilization pond southeast of Jewell, June 10, 1966; reaeration required on 2nd, 6th and 8th days.

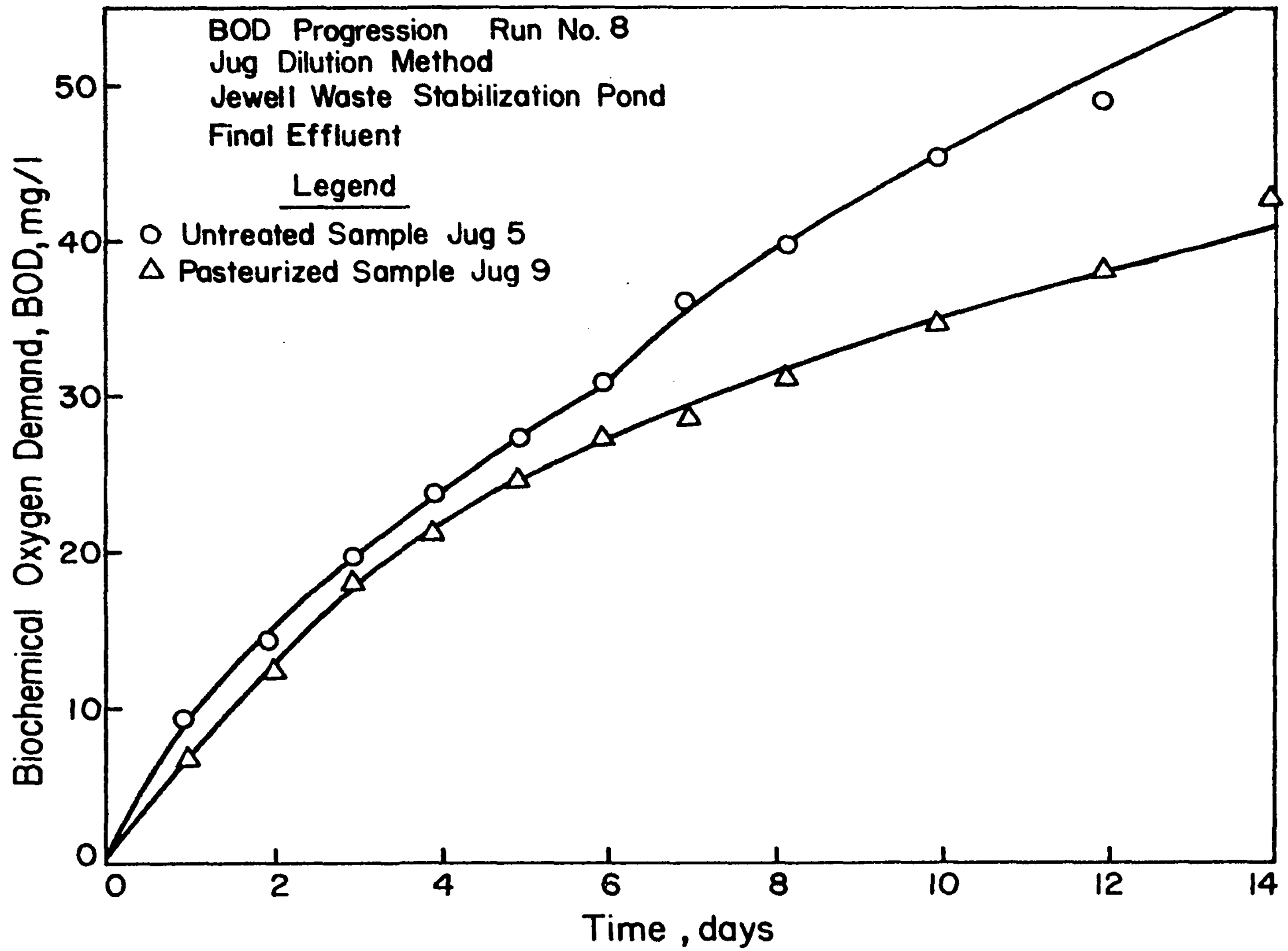

Fig. 44. BOD progression for the effluent from a waste stabilization pond, Jewell, Iowa, Run No. 8.

E. Mathematical Analysis of BOD Progression

1. Methods of study

The results obtained in these studies indicated that nitrification not only influenced the BOD progression, but the level of dissolved oxygen and reaeration problems were added factors in causing somewhat erratic fluctuations in the results. The more consistent data for (1) the combined carbonaceous and nitrogenous BOD studies and (2) the carbonaceous BOD data (corrected for nitrification) were used in the mathematical analysis. Both the experimental BOD data and BOD values obtained from the faired curves were included in the evaluation of BOD progression. The former data were used to verify trends and the faired curve data introduced to provide more accurate comparisons.

The mathematical analyses reported in this section were directed towards three aspects of BOD progression. These were: (1) determination of the temporal changes (or constancy) of the variables k (or K_1) and L_a in the first-order mathematical model for BOD (Eqs. 11-13); (2) evaluating new or additional relationships for improving the estimating ability of the first-order reaction; and (3) comparing the adequacy of the several mathematical models including the second-order reaction to forecast the progression of BOD. These were presented previously as Eqs. 11-13 and 16-21. The objective of this investigation was to determine if one of the mathematical models was definitely superior to the others, or if all were an adequate means of simulating the actual but complex biological reactions involved in the progression of BOD.

Additional evaluation of raw sewage BOD progression was included in the analysis to support the initial indication of considerable variation of K_1 and L_a with time. Data obtained from published reports and unpublished data from an analysis of BOD of the contents of an agricultural waste lagoon at Iowa State University were used in this added study phase.

2. <u>Temporal analysis of the BOD first-order parameters using computer programs</u>

Equation 13 contains two unknowns, k (or K_1) and L_a, requiring a minimum of two observations in a time series to yield singular solutions for the two variables. For two successive values of BOD in the time series, the following equality can be formed using Eq. 13 as the basis:

$$\frac{y_2}{y_1} = \frac{(1 - 10^{-K_1 t_2})}{(1 - 10^{-K_1 t_1})} \qquad (109)$$

where

y_1, y_2 are the values of BOD at times t_1 and t_2, respectively,

K_1 is the coefficient of deoxygenation assumed to be constant for the time interval, $t_2 - t_1$, and

L_a, the ultimate BOD, is eliminated by the division process since it also is assumed to be constant for the time interval.

Once K_1 is evaluated as the only unknown in Eq. 109, L_a is computed using Eq. 13. Solution of Eq. 109 must be accomplished by trial and error, or an iterative process can be used in a digital computer program. A program labeled RXRATE was developed in the sanitary engineering section of Iowa State University to solve Eq. 109 and subsequently compute L_a (and k, base e) using Eq. 13 for successive values of BOD in a time series. The algorithm included in RXRATE is the half-interval method using predetermined values for the lower and upper bounds of K_1. Usually 20 (and no more than 40) iterations were sufficient to evaluate the coefficient to the fourth place with a lower bound of 0.001 and an upper bound of 2 to 4.

The laboratory experimental results were analyzed first, and then the faired curve data were evaluated. A second computer program, BODMM, was developed for obtaining the time average values of k, K_1, and L_a using the method of moments (Eqs. 17 and 18). Because the use of Eqs. 17 and 18 in combination to provide a solution for the time average value of k or K_1 results in an equation similar to Eq. 109 above, the half-interval iterative sequence was also included in this program. The results of (1) the temporal variations in k, K_1, and L_a and (2) the time average values for the entire test period will be presented together in this section permitting visual comparison of the overall results.

3. <u>Results of mathematical analysis of the experimental data</u>

The temporal variations of K_1 and L_a for final effluents from the Ames (Run No. 6), Marshalltown, and Jewell treatment facilities were first computed from the laboratory data prior to curve smoothing. The results are listed in Tables 55 and 56. Although the laboratory data do not define a smooth progression of BOD, the general trend for K_1 values to decrease and for L_a values to increase is evident. For some laboratory data, as listed in Table 55, no value for K_1 is obtained,

Table 55. Temporal variation of K_1 and L_a using laboratory data of Run No. 6, Ames final effluent

	Final effluent sample							Pasteurized final effluent sample					
	Jug dilution unit 1			Jug dilution unit 3				Jug dilution unit 5			Jug dilution unit 9		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l	Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
0.92	15.0			14.0			0.92	10.5			10.8		
		0.466	23.9		0.148	52.1			0.326	21.1		0.452	17.5
1.90	20.8			24.8			1.90	16.0			15.1		
		0.050	105.0		0.145	52.7			-[a]	-[a]		0.147	31.8
2.85	29.6			32.4			2.85	23.2			19.7		
		0.053	100.2		0.089	73.2			0.167	34.9		0.122	35.8
4.08	39.5			41.5			4.08	27.6			24.4		
		-[a]	-[a]		-[a]	-[a]			0.315	29.1		-[a]	-[a]
4.94	48.1			50.6			4.94	28.3			29.6		
		0.122	64.0		0.077	87.0			-[a]	-[a]		0.102	43.1
5.85	51.7			56.0			5.85	34.8			32.2		
		-[a]	-[a]		0.031	163.0			0.112	44.7		0.146	37.5
6.93	61.7			64.0			6.93	37.2			33.8		
		0.024	192.2		0.057	107.0			0.127	42.8		0.062	53.6
7.83	68.1			68.8			7.83	38.5			36.2		
Avg. for period[b]		0.052	108.1		0.062	100.4			0.109	44.0		0.110	40.9

[a]Solution not determined because K_1 is negative (or $- K_1t$ is positive), program outputs "no solution."

[b]Solution of K_1 and L_a using method of moments, Eqs. 17 and 18, for the entire test period values.

Table 56. Temporal variation of K_1 and L_a computed from laboratory data of Runs No. 7 and 8, Marshalltown and Jewell final effluents

	Marshalltown activated sludge plant effluent							Jewell waste stabilization pond effluent					
	Untreated sample			Pasteurized sample				Untreated sample			Pasteurized sample		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l	Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
0.92	3.52			1.82			0.96	9.16			6.66		
		0.283	7.80		0.115	8.39			0.254	21.3		0.079	41.8
1.94	5.60			3.38			1.92	14.38			12.26		
		0.044	31.1		0.149	6.97			0.102	39.5		0.040	74.8
2.94	8.08			4.42			2.96	19.84			18.04		
		0.060	24.1		0.049	15.6			0.098	40.6		0.138	29.6
3.89	10.06			5.56			3.92	23.90			21.08		
		0.030	42.4		0.086	10.4			0.103	39.4		0.072	44.0
4.94	12.34			6.46			4.96	27.30			24.72		
									0.059	55.5		0.090	38.5
							5.96	30.90			27.30		
									0.024	110.9		0.119	34.0
							6.92	35.00			28.84		
									0.028	97.3		0.079	40.2
							8.17	39.82			31.16		
									0.038	78.5		0.050	51.1
							9.94	45.32			34.84		
Avg. for period[a]		0.076	20.8		0.095	9.68			0.063	56.6		0.083	40.0

[a]Solution of K_1 and L_a using method of moments, Eqs. 17 and 18, for the entire test period values.

since the computer iteration is bypassed if a negative K_1 is sensed. For this condition to occur, the two data points infer an exponential growth curve rather than a decay process (BOD progression increases without bound instead of having a horizontal asymptote). Graphically, if the slope of the line connecting two BOD data points intersects the abscissa rather than the ordinate (as referenced to zero values), then only an exponential growth curve can be fitted to the three points (zero included).

The values of the time average analysis of the data for K_1 and L_a, using the method of moments, is included at the bottom of each table. Inspection and comparison of the results shows that the time average values of K_1 and L_a are median or approximate arithmetic averages of the temporal values of each. Of interest is the fact that the value of L_a computed using the method of moments is higher than any of the daily BOD values, as could be expected, but is lower than the highest temporal values of L_a computed on a day-by-day or time point-by-point basis.

The laboratory data for all runs were plotted on large-scale graph paper and smooth curves faired to the plotted points. Even-day BOD values were extracted and used in the RXRATE computer program to determine the temporal variations in K_1 and L_a for the smoothed BOD progression. The results of Runs 4 through 8 are summarized in Tables 57 through 61. These include the three test periods for the Ames final effluent, and one each for the Marshalltown and Jewell effluents.

The results show a much more consistent trend in the decreasing nature for K_1 values and the increasing nature of the L_a values. For

Table 57. Temporal variation of K_1 and L_a using faired curve data, Run No. 4, Ames final effluent

	Final effluent stirred samples			Final effluent unstirred samples			BOD bottle dilution control		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
1	17.2			15.0			15.0		
		0.135	64.3		0.155	50.0		0.155	50.0
2	29.8			25.5			25.5		
		0.108	76.3		0.121	59.5		0.115	62.1
3	40.0			33.8			34.0		
		0.083	91.9		0.111	63.0		0.081	79.0
4	49.0			40.4			41.7		
		0.067	106.2		0.092	70.9		0.071	86.6
5	57.2			46.2			48.5		
		0.053	124.8		0.074	80.8		0.056	102.6
6	65.0			51.6			55.0		
		0.052	127.4		0.066	86.5		0.050	110.0
7	72.0			56.5			61.0		
Avg. for period[a]		0.076	100.1		0.101	69.1		0.079	82.6

[a]Solution of K_1 and L_a using the method of moments, Eqs. 17 and 18, for the entire test period values.

Table 58. Temporal variation of K_1 and L_a using faired curve data, Run No. 5, Ames final effluent

	Final effluent			Pasteurized final effluent		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
1	23.5			13.0		
		0.241	55.2		0.160	42.2
2	37.0			22.0		
		0.122	85.8		0.128	49.5
3	49.0			29.0		
		0.083	112.1		0.117	52.2
4	60.0			34.5		
		0.052	156.9		0.075	69.2
5	71.0			40.0		
		0.062	137.7		0.065	76.1
6	80.0			45.0		
		0.060	142.0		0.060	79.9
7	88.0			49.5		
		0.047	166.6		0.058	81.5
8	96.0			53.5		
		0.049	161.8		0.058	81.5
9	103.0			57.0		
		0.040	182.1		0.059	80.4
10	110.0			60.0		
Avg. for period[a]		0.067	136.0		0.077	70.6

[a]Solution of K_1 and L_a using the method of moments, Eqs. 17 and 18, for the entire test period values.

Table 59. Temporal variation of K_1 and L_a using faired curve data, Run No. 6, Ames final effluent

	Final effluent			Pasteurized final effluent		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
1	13.5			10.5		
		0.109	60.8		0.243	24.5
2	24.0			16.5		
		0.082	76.3		0.115	40.2
3	33.0			22.0		
		0.055	104.7		0.102	43.5
4	41.5			26.5		
		0.054	105.0		0.096	45.2
5	49.0			30.2		
					0.078	50.8
6				33.6		
					0.069	54.7
7				36.7		
					0.064	57.3
8				39.5		
					0.058	60.5
9				42.1		
					0.057	60.9
10				44.4		
					0.057	60.6
11				46.4		
					0.053	63.1
12				48.3		
					0.052	63.4
13				50.0		
					0.056	61.6
14				51.4		
					0.050	64.3
15				52.8		
					0.055	62.0
16				53.9		
					0.050	64.0
17				55.0		
					0.049	64.3
18				56.0		
					0.049	64.4
19				56.9		
					0.049	64.4
20				57.7		

Table 59. Cont.

Day	Final effluent BOD, mg/l	Final effluent K_1, per day	Final effluent L_a, mg/l	Pasteurized final effluent BOD, mg/l	Pasteurized final effluent K_1, per day	Pasteurized final effluent L_a, mg/l
Avg. for period[a]		0.070	88.0		0.063	59.6

[a]Solution of K_1 and L_a using method of moments, Eqs. 17 and 18, for the entire test period values.

Table 60. Temporal variation of K_1 and L_a using faired curve data, Run No. 7, Marshalltown final effluent

	Final effluent			Pasteurized final effluent		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
1	3.40			2.00		
		0.116	14.5		0.125	8.00
2	6.00			3.50		
		0.088	18.0		0.107	8.99
3	8.20			4.70		
		0.051	27.6		0.094	9.83
4	10.35			5.70		
		0.040	33.9		0.086	10.45
5	12.40			6.55		
		0.037	35.4		0.076	11.20
6	14.30			7.30		
					0.073	11.51
7				7.95		
					0.064	12.30
8				8.55		
					0.059	12.85
9				9.10		
					0.056	13.21
10				9.60		
Avg. for period[a]		0.058	25.5		0.078	11.26

[a]Solution of K_1 and L_a using method of moments, Eqs. 17 and 18, for the entire test period values.

Table 61. Temporal variation of K_1 and L_a using faired curve data, Run No. 8, Jewell waste stabilization pond effluent

	Final effluent			Pasteurized final effluent		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
1	9.1			7.2		
		0.167	28.6		0.109	32.4
2	15.3			12.8		
		0.133	33.3		0.088	38.4
3	20.1			17.5		
		0.108	38.3		0.089	37.8
4	24.1			21.3		
		0.090	42.8		0.084	39.4
5	27.6			24.5		
		0.083	44.8		0.086	39.0
6	30.6			27.1		
		0.078	46.4		0.078	41.1
7	33.2			29.4		
		0.069	49.6		0.070	43.6
8	35.6			31.5		
		0.059	53.7		0.065	45.2
9	37.9			33.4		
		0.056	55.3		0.058	47.8
10	40.0			35.2		
		0.050	58.2		0.057	48.3
11	42.0			36.8		
		0.046	60.7		0.053	49.9
12	43.9			38.3		
		0.043	62.8		0.046	53.2
13	45.7			39.8		
		0.041	64.5		0.044	54.3
14	47.4			41.2		
Avg. for period[a]		0.071	50.8		0.069	44.8

[a]Solution of K_1 and L_a using method of moments, Eqs. 17 and 18, for the entire test period values.

the Ames final effluent, the range in daily values of K_1 is from 0.05 to 0.24, the latter value being observed on the first to second day. Average K_1 values for the entire test period, as determined by the method of moments, are in close comparison, 0.06 to 0.08 with one value of 0.10. Again, it is noted that the average L_a value is between the highest recorded BOD value and the highest daily L_a magnitude. The ultimate BOD, L_a, of the pasteurized samples varies from 60 to 70 mg/l. Values for the unpasteurized samples show more variation, as might be expected under the influence of nitrification.

Values of K_1, temporally, show the same decreasing effect for the Marshalltown and Jewell effluents. The time average K_1 values approximate those experienced at Ames, 0.06 to 0.08. Generally speaking, the lower the value of K_1 for the various test periods, the greater is the value of L_a. The average L_a values for the Marshalltown effluent are very low, providing a measure of the real effectiveness of the activated sludge process for removal of carbonaceous BOD from municipal waste.

4. Results of mathematical analysis of raw sewage data

The experimental results confirm that the rate of BOD progression for final effluents is not precisely a first-order reaction. Additional evaluation was then made of the BOD progression of raw sewage samples, using previously published data. Four municipal or industrial wastes were selected to illustrate the temporal variation of K_1 and L_a for higher strength raw wastes. The three examples of municipal wastes include the Baltimore, Maryland, water pollution control plant influent (Keefer, 1961), the discharge from a housing development at Rutgers, New Jersey (Orford et al., 1953), and a weak municipal sewage at Houston, Texas (Busch, 1958). An agriculture waste was represented by the contents of a lagoon serving a confined swine feeding unit at Iowa State University (Oulman, 1967). The time period for the reported BOD data varied from 5 to 10 days. Data from graphs (faired curve values) and tabular values of laboratory determinations were both used in the study.

The average faired curve data are listed in Table 62. The same trends for K_1 and L_a are clearly evident. However, the initial K_1 values in the temporal analysis are much higher, varying from 0.34 to more than 0.50 for the four wastes. The time average values of K_1 for the four wastes are in fair agreement, 0.24 to 0.30. However, these values are over three times the magnitude of the average K_1 values for the final effluents. In this analysis of the raw sewage data, the time average values of L_a for the various test periods are just slightly higher than the final BOD reading, and for one the L_a value is slightly lower.

The data for the Rutgers raw sewage, represented a strictly domestic sewage. Data was included in the report for the initial 2 days of BOD progression which upon analysis provided the following results:

Day	BOD, mg/l	K_1, per day	L_a, mg/l
0.41	107.6		
		0.805	202.1
0.96	168.0		
		0.540	241.0
1.98	220.5		
		0.278	307.1
4.06	284.2		
		0.182	347.7
4.98	304.5		

Table 62. Temporal variation of K_1 and L_a for raw municipal sewage and contents of an agricultural lagoon, based upon faired curve results[a]

	Baltimore, Maryland, raw sewage			Rutgers, New Jersey, raw sewage			Houston, Texas, raw sewage			Contents of the I.S.U. swine waste lagoon		
Day	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
1	48			169			53			545		
		0.359	85.3		0.504	246		0.363	93.6		0.338	1,007
2	69			222			76			795		
		0.290	93.6		0.323	287		0.338	96.4		0.243	1,180
3	81			256			87			960		
		0.201	108.0		0.230	322		0.255	105.0		0.215	1,242
4	91			283			95			1,070		
		0.149	122.1		0.191	342		0.239	106.8		0.219	1,234
5	100			304			100			1,135		
					0.195	340						
6				317								
					0.188	343						
7				326								
					0.173	347						
8				333								
					0.184	345						
9				337								
					0.200	342						
10				339								

[a]Source of data: Keefer (1961); Orford et al. (1953); Busch (1958); Oulman (1967), respectively.

Table 62. Cont.

Day	Baltimore, Maryland, raw sewage			Rutgers, New Jersey raw sewage			Houston, Texas, raw sewage			Contents of the I.S.U. swine waste lagoon		
	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l	BOD, mg/l	K_1, per day	L_a, mg/l
Avg. for period[b]		0.250	102.6		0.241	333		0.306	101.4		0.251	1,187

[b]Solution of K_1 and L_a using method of moments, Eqs. 17 and 18, for the entire test period values.

This initial K_1 value, 0.805, was the highest of the computed values for all data, and illustrates the rapid oxidation of the carbonaceous BOD which takes place initially in a raw sewage. For the 8 days of BOD data from which the above 5 values were extracted, the time average values of K_1 and L_a were 0.314 and 321, respectively. These results differ slightly from the results shown in Table 62 which were based on faired curve values.

The analysis of the data for raw sewage confirms the results obtained for the final effluents regarding the temporal variations in K_1 and L_a. If the BOD progression is assumed to be first order for small increments of time, then it appears that the most easily oxidized substances are attacked first at a rapid rate, and assimilated or at least adsorbed from solution. The remaining substances and/or the adsorbed organics are then consumed biologically at a slower rate. Because the progression of BOD does not follow the first-order reaction, additional mathematical models were studied.

5. Development of the modified monomolecular model

The primary attributes (Imhoff and Fair, 1929) that any mathematical model of BOD progression must possess are (1) a limiting or ultimate value of oxygen consumed and (2) a rate constant or proportionality per unit of time. Within this framework, a modified monomolecular model for simulating the observed progression of BOD of a waste sample was developed. The primary goal was an improvement in the ability to predict the observed BOD and to forecast better the values of BOD as they approach the ultimate value.

The approach first involved a statistical analysis of the temporal variation of K_1 and L_a. The following empirical relationships were selected after initial study of other relationships failed to provide satisfactory correlation of the variables involved:

$$L_a = aa + \frac{t}{a + bt} \tag{110}$$

and

$$K_1 = ct^{-d} \tag{111}$$

where

t = time at the middle of the time interval for which observed values of K_1 and L_a are used, and

aa, a, b, c and d are constants.

The use of Eq. 110 for representing L_a provides an initial value of L_a = aa, and a limiting value with time of (aa + 1/b). This is in agreement with the attributes listed above, for L_a, and gives a rate constant that decreases with time. If the constant aa is not used, or is of zero value, then L_a has the initial value of zero, an unlikely event for normal wastes. Equations 110 and 111 were linearized for statistical analysis by appropriate transformations. A sequence of values was assigned for the constant aa in each analysis, ranging from zero to about three times the first day's BOD value.

Development of the modified monomolecular model for predicting BOD, using Eqs. 110 and 111, proceeded on the basis that the two component equations could be used in the form of the original first-order BOD model (Eq. 13). To represent the true temporal variability of BOD as expressed in Eqs. 13, 110, and 111, an incremental computation system had to be developed. Increments of BOD, computed for successive time periods, could then be summed to provide the total BOD for any selected time period. If t represents the beginning of a time period, and dt is the incremental time period, then an increment of BOD is computed in the following manner. First, values of K_1 and L_a are computed using

$$L_a = aa + \frac{(t + dt/2)}{a + b(t + dt/2)} \tag{110a}$$

and

$$K_1 = c(t + \frac{dt}{2})^{-d} \tag{111a}$$

Using Eq. 13, an increment of BOD is computed as a difference,

$$\begin{aligned} dy &= y_{t+dt} - y_t \\ &= L_a[10^{-K_1 t} - 10^{-K_1(t+dt)}] \end{aligned} \tag{112}$$

The total BOD at the end of the time period, for the time t + dt, is obtained using a summation equation for the dy values of Eq. 112,

$$y = \sum_{t=0}^{t+dt} L_a[10^{-K_1 t} - 10^{-K_1(t+dt)}] \tag{113}$$

This mathematical model was given the title of "modified monomolecular model" to distinguish it from Eq. 13. Equations 110 through 113 constitute the components of this mathematical model. The BOD data for the various test periods in the laboratory experimental program were analyzed with this model, as were the raw sewage data. As noted previously, Eq. 110 contains three constants; regression analysis was made using assumed values of aa. Once the constants were evaluated through regression analysis, the BOD progression could be simulated for the observed time data points. A digital computer program, BODMOD, was developed to permit this simulation and also to calculate the differences between observed and computed results. The average difference and the sum of the squares of the differences (and related standard deviation) were also calculated. The values of aa, a, and b adopted ex post facto through this analysis were those that produced the lowest error as measured with the sum of the squares of the differences between observed and computed BOD values.

6. Comparative results obtained with the several mathematical models

Additional comparison was made for the BOD progression analysis using both Eqs. 16 and 21. The former is the Thomas method for computing the time average values of K_1 and L_a, and the latter is the second-order mathematical model. Logarithmic equations were not considered in this study, since it has previously been shown that they were inferior to the second-order model (Woodward, 1953). A series equation was studied briefly, since it is in common use in chemistry applications and was used also in the evaluation of saturated dissolved oxygen variations with temperature (Committee on Sanitary Engineering Research, A.S.C.E., 1960). Although excellent correlation can be achieved within the period of observations, the series model is absolutely unpredictable beyond that period. For example, if constants evaluated with 5 days of data were used to predict for a 20-day period, frequently negative BOD values would be computed by the end of the longer period. Because this model lacks the required attributes for a BOD model, it was not considered further.

The BOD progression data for both the experimental results using final effluents and the raw sewage BOD values were introduced as input data for mathematical analysis. The following mathematical models were included in the study:

(1) First-order or monomolecular model

a. Method of moments, Eqs. 17 and 18

b. Thomas method, Eq. 16

(2) Modified monomolecular model, Eqs. 110-113

(3) Second-order relationship and associated model, Eq. 21

a. Data manipulation procedures As noted above, a separate computer program was developed for each of the models selected for study. Three of the four models require statistical treatment of the BOD data for evaluation of the appropriate constants. The MAIDS regression program available in the sanitary engineering section, Department of Civil Engineering, was used in these determinations. Once the constants were evaluated, they were included with the observed BOD values as input data for the specific computer program. The separate computer programs were labeled BODMM, BODTH, BODMOD, and BODSO for the method of moments, the Thomas method, the modified monomolecular, and the second-order models, respectively.

The computer programs were designed to calculate the BOD for the same time period data points as read in with the observed BOD data. The magnitude and percent difference between observed and computed values were determined and included as output, along with the percent BOD completion based on the ultimate value of BOD, L_a. The average difference (zero for the method of moments), the sum of squares of the differences, the standard deviation of the differences, the average percent difference, and the standard deviation of the percent differences were computed in the final phases of the program operation sequence. This provided a statistical summary for determining (1) the value of aa for the modified monomolecular model, Eq. 111, and (2) the best predictor of all of the four models studied. The computer programs also calculated the BOD progression for a 20-day period to permit long-term inspection and evaluation of the rapidity with which the ultimate BOD value, L_a, was reached.

The results showed that the method of moments consistently gave a better measure of prediction than did the Thomas method. Therefore, the results of the latter will be included in the tabulations or discussion, since both are for the first-order reaction.

b. Results of the mathematical analysis All of the raw sewage and final effluent BOD data were processed using the computer programs. For the long-term studies involving up to 10 to 20 days, the effect of varying length of test period was introduced, using 5-, 10-, and 20-day periods. The effect was also studied using 1/2-day periods instead of 1-day periods in the analysis of the swine waste lagoon contents. Except for the initial run (Run No. 4) of the Ames final effluent, only the results of the carbonaceous BOD progression obtained through pasteurization of the effluent samples are included in the summary tables because of the volume of data and results generated in the computer programming. The data for the four high-strength wastes are also included in the tabulated data.

Comparative results for the prediction capability of the three selected mathematical models (first order, modified monomolecular, and second order) are tabulated in Tables 63 through 71. Results for the Ames, Marshalltown, and Jewell effluents are included in Tables 63 through 67. Results for the three municipal raw wastes (Baltimore, Maryland, Rutgers, New Jersey, and Houston, Texas) are included in Tables 68 through 70. Results for the I.S.U. swine waste lagoon contents are listed in Table 71. These tables include the observed and computed BOD results, the statistical summaries, and the constants evaluated in the analysis.

c. Discussion and summary The statistical summary included in each table provides the quantitative measure of the predictive capability of the three mathematical models. As noted by Theriault (1927), the best predictor should minimize the variance or differences between the observed and computed values. The sum of the squares of the differences, and its associated standard deviation, provides this measure. In all runs except three, the modified monomolecular model provides the superior prediction. In these three cases, it is only slightly less capable than the second-order model.

It appears to be significant that either the modified monomolecular model or the second-order model provides the best prediction, and the first-order reaction always has the greatest variance. Equally as important, however, is the fact that all three can predict any specific data point within an accuracy of 10%. In view of the unpredicability of most biological processes in which precise estimates of the progression of events is seldom possible, this means that any of the three models is

Table 63. Comparison of the prediction capability of three mathematical models of BOD progression, Ames final effluent, Run No. 4[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model: First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	17.2	16.01	17.35	16.52
	2	29.8	29.46	29.48	29.86
	3	40.0	40.76	39.86	40.87
	4	49.0	50.25	49.08	50.10
	5	57.2	58.23	57.42	57.96
	6	65.0	64.93	65.03	64.73
	7	72.0	70.55	72.04	70.62
K_1 or k"			0.076		0.119
L_a or L'_a			100.1	229.8	155.5
aa				17.70	
a				0.0284	
b				0.00472	
c				0.191	
d				0.703	
Avg. difference			0.0	0.008	0.067
Sum of squares of differences			6.840	0.203	5.010
Standard deviation of differences			1.068	0.184	0.914

[a]Final effluent, stirred samples; see Tables 47 and 57.

Table 64. Comparison of the prediction capability of three mathematical models of BOD progression, Ames final effluent, Run No. 5[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	13.0	11.45	13.01	12.09
	2	22.0	21.04	21.72	21.66
	3	29.0	29.08	28.87	29.42
	4	34.5	35.81	34.99	35.83
	5	40.0	41.46	40.35	41.23
	6	45.0	46.19	45.12	45.83
	7	49.5	50.15	49.39	49.79
	8	53.5	53.47	53.27	53.25
	9	57.0	56.26	56.80	56.30
	10	60.0	58.59	60.04	58.99
K_1 or k"			0.0768		0.132
L_a or L'_a			70.65	116.8	103.7
aa				13.80	
a				0.0422	
b				0.00971	
c				0.214	
d				0.627	
Avg. difference			0.0	0.007	0.088
Sum of squares of differences			11.578	0.584	6.731
Standard deviation of differences			1.134	0.255	0.865

[a]Final effluent, pasteurized sample; see Tables 48 and 58.

Table 65. Comparison of the prediction capability of three mathematical models of BOD progression, Ames final effluent, Run No. 6[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model: First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	10.5	8.03	10.43	9.01
	2	16.5	14.97	17.14	16.20
	3	22.0	20.99	22.48	22.07
	4	26.5	26.19	26.95	26.95
	5	30.2	30.69	30.78	31.05
	6	33.6	34.58	34.12	34.61
	7	36.7	37.95	37.07	37.67
	8	39.5	40.87	39.68	40.34
	9	42.1	43.39	42.03	42.70
	10	44.4	45.58	44.15	44.79
	11	46.4	47.47	46.07	46.66
	12	48.3	49.10	47.83	48.35
	13	50.0	50.52	49.43	49.87
	14	51.4	51.74	50.91	51.25
	15	52.8	52.80	52.27	52.51
	16	53.9	53.72	53.54	53.67
	17	55.0	54.51	54.71	54.73
	18	56.0	55.20	55.80	55.72
	19	56.9	55.79	56.82	56.62
	20	57.7	56.31	57.77	57.47
K_1 or k"			0.0628		0.127
L_a or L'_a			59.61	77.24	80.16
aa				13.60	
a				0.0648	
b				0.0157	
c				0.213	
d				0.539	
Avg. difference			0.0	-0.021	0.093
Sum of squares of differences			23.54	3.134	6.986
Standard deviation of differences			1.113	0.406	0.606

[a]Final effluent, pasteurized sample; see Tables 50 and 59.

Table 66. Comparison of the prediction capability of three mathematical models of BOD progression, Marshalltown final effluent, Run No. 7[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model: First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	2.00	1.86	2.02	1.94
	2	3.50	3.41	3.47	3.48
	3	4.70	4.70	4.65	4.73
	4	5.70	5.78	5.66	5.76
	5	6.55	6.68	6.53	6.63
	6	7.30	7.44	7.30	7.37
	7	7.95	8.07	7.97	8.01
	8	8.55	8.59	8.57	8.56
	9	9.10	9.03	9.11	9.05
	10	9.60	9.40	9.59	9.49
K_1 or k"			0.0782		0.132
L_a or L'_a			11.26	16.30	16.70
aa				3.60	
a				0.271	
b				0.0787	
c				0.158	
d				0.437	
Avg. difference			0.0	-0.007	0.007
Sum of squares of differences			0.133	0.007	0.036
Standard deviation of differences			0.122	0.027	0.064

[a]Final effluent, pasteurized sample, activated sludge process; see Tables 52 and 60.

Table 67. Comparison of the prediction capability of three mathematical models of BOD progression, Jewell final effluent, Run No. 8[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model: First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	7.2	6.61	7.57	7.06
	2	12.8	12.24	12.85	12.71
	3	17.5	17.05	17.19	17.35
	4	21.3	21.14	20.90	21.22
	5	24.5	24.63	24.12	24.49
	6	27.1	27.61	26.95	27.30
	7	29.4	30.14	29.46	29.74
	8	31.5	32.30	31.70	31.88
	9	33.4	34.15	33.70	33.76
	10	35.2	35.72	35.50	35.44
	11	36.8	37.05	37.14	36.94
	12	38.3	38.20	38.62	38.29
	13	39.8	39.17	39.97	39.52
	14	41.2	40.00	41.21	40.63
K_1 or k''			0.0693		0.124
L_a or L'_a			44.79	62.41	64.07
aa				17.00	
a				0.0954	
b				0.0220	
c				0.142	
d				0.392	
Avg. difference			0.0	0.063	0.024
Sum of squares of differences			5.094	1.023	0.979
Standard deviation of differences			0.626	0.281	0.274

[a]Final effluent, pasteurized sample, waste stabilization process; see Tables 54 and 61.

Table 68. Comparison of the prediction capability of three mathematical models of BOD progression, Baltimore, Maryland, raw sewage[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	48.	44.98	48.31	46.51
	2	69.	70.25	68.01	69.37
	3	81.	84.45	81.48	82.96
	4	91.	92.42	91.82	91.97
	5	100.	96.90	100.20	98.38
K_1 or k"			0.250		0.517
L_a or L'_a			102.6	176.0	136.4
aa				35.0	
a				0.0217	
b				0.00709	
c				0.533	
d				0.799	
Avg. difference			0.0	0.164	0.037
Sum of squares of differences			34.178	2.009	9.762
Standard deviation of differences			2.923	0.709	1.562

[a]Data obtained from Keefer (1961); see Table 62.

Table 69. Comparison of the prediction capability of three mathematical models of BOD progression, Rutgers, New Jersey, raw sewage[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model: First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	169	141.8	166.5	159.4
	2	222	223.3	229.2	226.5
	3	256	270.2	264.5	263.4
	4	283	297.1	287.1	286.8
	5	304	312.6	302.6	302.9
	6	317	321.5	313.8	314.7
	7	326	326.6	322.2	323.7
	8	333	329.5	328.6	330.8
	9	337	331.2	333.6	336.6
	10	339	332.2	337.6	341.3
K_1 or k"			0.241		0.689
L_a or L'_a			333.5	381.5	390.9
aa				140.0	
a				0.00577	
b				0.00414	
c				0.514	
d				0.521	
Avg. difference			0.0	-0.032	0.015
Sum of squares of differences			1,326.4	205.2	202.6
Standard deviation of differences			12.140	4.775	4.745

[a]Faired curve data, original data from Orford et al. (1953); see Table 62.

Table 70. Comparison of the prediction capability of three mathematical models of BOD progression, Houston, Texas, raw sewage[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	53.	51.31	53.06	53.35
	2	76.	76.66	75.31	75.33
	3	87	89.19	87.58	87.33
	4	95	95.39	95.12	94.88
	5	100.	98.45	100.04	100.07
K_1 or k"			0.306		0.714
L_a or L'_a			101.4	118.7	128.1
aa				44.0	
a				0.0116	
b				0.0134	
c				0.446	
d				0.408	
Avg. difference			0.0	0.024	-0.009
Sum of squares of differences			10.68	0.838	0.695
Standard deviation of differences			1.634	0.458	0.417

[a]Data obtained from Busch (1958); see Table 62.

Table 71. Comparison of the prediction capability of three mathematical models of BOD progression, contents of I.S.U. agricultural waste lagoon[a]

Item	Day	Observed BOD, mg/l	Computed BOD, mg/l, for indicated model: First-order reaction	Modified monomolecular	Second-order reaction
BOD run	1	545	521.7	544.2	540.2
	2	795	814.1	803.1	804.0
	3	960	978.0	959.5	960.4
	4	1,070	1,069.8	1,062.8	1,063.8
	5	1,135	1,121.3	1,134.8	1,137.3
K_1 or k"			0.251		0.524
L_a or L'_a			1,187.0	1,447.0	1,571.5
aa				496.0	
a				0.00119	
b				0.00105	
c				0.382	
d				0.418	
Avg. difference			0.0	-0.135	0.121
Sum of squares of differences			1,418.5	118.273	148.344
Standard deviation of differences			18.831	5.438	6.090

[a]Contents of a swine waste lagoon for a confined feeding unit, data obtained from Oulman (1967); see Table 62.

satisfactory. Simplicity then becomes a criterion for applicability in mathematical analysis; this obviously favors the first-order reaction.

Additional verification of the ability of the modified monomolecular model to predict the observed BOD progression (in view of the component method of analyzing K_1 and L_a temporally) is provided in Tables 72 and 73. These four examples illustrate the relationship between observed temporal changes in K_1 and L_a, as evaluated from the faired curves of experimental or published results, and the computed values obtained using the computer program for the modified monomolecular model. The differences between observed and computed results are not as great in view of the empirical nature of the relationships selected to describe the temporal variations.

The last method of comparing the predictive capability of the three mathematical models was a test of the constancy of the equation constants in the respective models. Time intervals of 5- and 10-; 5-, 10- and 20-; and 5-, 10-, and 14-day periods were used in this comparison. In addition, the effect of using 1/2-day increments in the analysis in place of 1-day increments was also tested. The results of these analyses are listed in Table 74.

Inspection of the data in Table 74 discloses first that the effect of increasing the time period of analysis on the results obtained with the first-order model is exactly that forecast by other researchers (Orford et al., 1953; Orford and Ingram, 1953), in that the values of K_1 decrease and of L_a increase. Of the three models, the second-order model provides the greatest degree of constancy among the constants and their associated values. Little variation in the values of the constants

Table 72. Comparison of observed and computed values of the temporal variation in K_1 and L_a for the modified monomolecular model for BOD progression[a], using trickling filter effluent results

Day	Trickling filter effluent Run No. 4 Observed K_1 per day	Computed K_1 per day	Observed L_a mg/l	Computed L_a mg/l	Trickling filter effluent Run No. 6 Observed K_1 per day	Computed K_1 per day	Observed L_a mg/l	Computed L_a mg/l
1								
	0.135	0.143	64.3	60.0	0.243	0.171	24.5	30.6
2								
	0.108	0.100	76.3	79.9	0.115	0.130	40.2	37.6
3								
	0.0827	0.0791	91.9	95.7	0.102	0.108	43.5	42.8
4								
	0.0671	0.0663	106.2	108.4	0.0959	0.0946	45.2	60.6
5								
	0.0533	0.0576	124.8	119.0	0.0785	0.0849	50.8	64.7
6								
	0.0516	0.0512	127.4	127.8	0.0689	0.0776	54.7	68.0
7								
					0.0635	0.0719	57.3	70.8
8								
					0.0575	0.0671	60.5	73.1
9								
					0.0568	0.0632	60.9	75.1
10								

[a]Trickling filter effluent from the Ames water pollution control plant; see Tables 63 and 65.

Table 73. Comparison of observed and computed values of the temporal variation in K_1 and L_a for the modified monomolecular model for BOD progression[a], using an activated sludge effluent and domestic raw sewage results

	Activated sludge effluent Run No. 7				Domestic raw sewage Baltimore, Maryland			
Day	Observed K_1 per day	Computed K_1 per day	Observed L_a mg/l	Computed L_a mg/l	Observed K_1 per day	Computed K_1 per day	Observed L_a mg/l	Computed L_a mg/l
1								
	0.125	0.132	8.00	7.45	0.359	0.386	85.3	81.3
2								
	0.107	0.106	8.99	8.94	0.290	0.256	93.6	98.4
3								
	0.0941	0.0912	9.83	10.00	0.201	0.196	108.0	110.2
4								
	0.0856	0.0817	10.45	10.80	0.149	0.160	122.1	118.9
5								
	0.0763	0.0749	11.20	11.41				
6								
	0.0728	0.0696	11.51	11.90				
7								
	0.0645	0.0654	12.30	12.30				
8								
	0.0594	0.0619	12.85	12.64				
9								
	0.0564	0.0590	13.21	12.92				
10								

[a]Activated sludge effluent from the Marshalltown water pollution control plant (see Tables 52, 60 and 66); domestic raw sewage of Baltimore, Maryland, from data of Keefer (1961), see Tables 62 and 68.

Table 74. Variation of BOD constants with time period of analysis

Waste or effluent	Time interval (days)	Monomolecular model constants: K_1 (per day)	Monomolecular model constants: L_a (mg/l)	Second-order model constants: k" (per day)	Second-order model constants: L_a' (mg/l)	Modified monomolecular model, constants and coefficients: aa (mg/l)	L_a (mg/l)	a	b	c	d
Rutgers, N.J. Raw sewage	5	0.315	302.	0.729	382.	126.	491.	0.0085	0.0027	0.726	0.897
	10	0.241	333.	0.689	391.	140.	382.	0.0058	0.0041	0.514	0.521
Ames, Iowa Trickling filter, effluent	5	0.126	38.8	0.206	58.7	6.5	90.2	0.0563	0.0120	0.306	0.850
	10	0.085	50.2	0.150	72.3	9.1	91.9	0.0651	0.0121	0.275	0.732
	20	0.063	59.6	0.126	80.2	13.6	77.2	0.0648	0.0157	0.213	0.539
Marshalltown, Iowa Activated sludge, effluent	5	0.100	9.49	0.150	15.22	4.00	13.38	0.2233	0.1066	0.145	0.344
	10	0.078	11.26	0.132	16.70	3.60	16.30	0.2711	0.0787	0.158	0.437
Jewell, Iowa Waste stabilization pond, effluent	5	0.091	37.6	0.132	61.8	20.8	45.7	0.0592	0.0401	0.115	0.217
	10	0.080	41.2	0.132	61.6	19.7	53.1	0.0851	0.0299	0.125	0.290
	14	0.069	44.8	0.124	64.1	17.0	62.4	0.0954	0.0220	0.142	0.392

Table 74. Cont.

Waste or effluent	Time interval (days)	Monomolecular model constants K_1 (per day)	L_a (mg/l)	Second-order model constants k" (per day)	L'_a (mg/l)	Modified monomolecular model, constants and coefficients aa (mg/l)	L_a (mg/l)	a	b	c	d
I.S.U. Agr. Farm Swine wastes, lagoon contents	5[a]	0.251	1187.	0.524	1571.	496.	1447.	0.0012	0.0011	0.382	0.418
	5[b]	0.267	1164.	0.533	1544.	336.	1492.	0.0010	0.0009	0.433	0.534

[a]One-day intervals.

[b]One-half-day intervals.

is noted with the increase in length of test period except for the trickling filter effluent. The small variations noted in the second-order constants have the same trend as the first order, with k" decreasing and L'_a increasing. The modified monomolecular model was erratic in this regard, with some values increasing and others decreasing. The effect of using 1/2-day increments in place of 1-day increments provided less variation in the results than did the change in length of the test period.

F. Summary and Conclusions from the Effluent Studies

The experimental studies conducted in this phase of the research program demonstrate that the jug dilution method of conducting long-term studies of the behavior of effluents (and possibly of raw sewage) provides satisfactory results. However, reaeration presents a definite problem and limits the usefulness of the method where nitrification of the waste is involved. Nitrification occurs in all domestic and municipal wastes, and in industrial wastes of high organic and ammonia content; therefore, studies extending longer than 10 days have little meaning. Corrections then must be made for the nitrification, and accuracy in evaluating the nitrogen content in diluted samples is difficult to achieve. Evaluation of the BOD progression of wastes and effluents having a substantial ammonia and/or organic nitrogen content requires equipment that assures proper mixing and a high level of dissolved oxygen to assure that nitrification is not suppressed. Otherwise, the measured BOD progression may be greater than the carbonaceous BOD demand, but less than the maximum BOD demand that would occur under optimum conditions. This in-between result will have little meaning or application.

The need for expressing the BOD of final effluents in two components, the carbonaceous and the nitrogenous demands, is clearly evident. The efficiency of the Ames water pollution control plant during the test periods studied is increased from 67 to 70% to 80%, if efficiency is measured in terms of the removal only of carbonaceous BOD. The nitrogenous BOD of waste water is usually greater in magnitude than is the carbonaceous BOD. For the Marshalltown final effluent, the effect is quite striking. The 16-day measured total BOD was over 60 mg/l; the ultimate carbonaceous BOD was only 10 to 12 mg/l. This indicates a nitrogenous BOD of about 5 times the carbonaceous BOD. The effect was about 2:1 for the Ames final effluent, as it had a higher carbonaceous BOD but lower nitrogenous BOD from nitrification of ammonia in the trickling filters. The results for the Jewell waste stabilization pond indicated that effluent BOD_5 and L_a values for ponds are comparable with the trickling filter results; good nitrification is achieved in summer periods.

This last observation illustrates some compensation as between the two processes, the trickling filter and activated sludge systems. The results of the experimental investigations conducted in this phase of the research in water quality show the "trade-offs" that are inherent with the two processes. The activated sludge process produces a highly polished effluent, of high clarity and low carbonaceous BOD. However, the amount of ammonia nitrification will be negligible at the low DO concentrations maintained in most aeration units (less than 2 mg/l normally). Therefore, the ammonia content of the effluent will be high. This not only implies a heavy nitrogenous oxygen demand on the stream (unless facultative organisms and algae use the ammonia directly), but increases the probability of exceeding the permissible ammonia standards for recreation and aquatic habitat waters. The latter has been established by the Iowa Water Pollution Control Commission at a level of 2 mg/l for Iowa streams.

Conversely, the trickling filter process yields an effluent with higher carbonaceous BOD but achieves a measure of nitrification of the effluent in the filters. Therefore, the total BOD may not differ much from that remaining in the activated sludge process. Inspection of the results for the Ames and Marshalltown effluents does not indicate this equality, since the Ames effluent has about 2 to 3 times more total BOD as is observed in the Marshalltown effluent. However, the ammonia levels in the activated sludge effluent were somewhat lower than might be expected, unless the organic nitrogen remains unoxidized through the plant cycle due to the low DO levels. If the total nitrogen (ammonia and organic nitrogen) in the Marshalltown effluent is used in computing the nitrogenous demand, then the difference between processes would not be as great.

As a rough measure of the trade-off which might be expected, as between the trickling filter (Ames data) and the activated sludge process (Marshalltown data), the following tabulation is presented:

Effluent item	Trickling filter process	Activated sludge process
1. Nitrogenous BOD		
Ammonia and organic nitrogen, mg/l - N	10 - 15	20 - 25
Equivalent oxygen demand, mg/l	45 - 70	90 - 110
2. Carbonaceous BOD		
Ultimate, L_a, value, mg/l	50 - 70	10 - 20
3. Total combined BOD, nitrogenous and carbonaceous, mg/l	95 - 140	100 - 130

This approximate BOD relationship represents summer conditions, in which one-half to two-thirds of the nitrogenous BOD of the trickling filter is oxidized in the filters, but the activated sludge process passes most of this demand on to the stream. The results imply that all of the ammonia must be nitrified in the stream. This may not be true since some algae use ammonia directly. The results do show that the activated sludge process would have little overall advantage unless lower effluent ammonia and organic nitrogen levels are achieved. The results also indicate a real need for collecting more plant operation data of the nitrogenous oxygen demand, and for studying the BOD progression for all seasons of the year.

Three mathematical models for forecasting BOD progression were studied using both the results collected in this study and published data. The results indicate that the first-order model, the modified monomolecular model, and the second-order model can predict the progression of BOD within the general accuracy inherent in biological phenomena and associated reactions. The modified monomolecular model provided the most accurate prediction, in terms of minimizing the sum of the squares of the differences. However, the analysis of the data and determination of the constants involved in the model are laborious and time consuming. Its lack of simplicity is not in its favor. The second-order model is a superior prediction model than is the first-order model. It has the added attribute of achieving a fair degree of constancy in the values of the constants as the time period of analysis is increased. However, little has been studied concerning the variation of the second-order constants (or coefficients) with temperature, as between wastes, etc. More study is needed to confirm the desirability of advocating this model for general use. Because the first-order mathematical model predicts within the general capability of duplicating or reproducing biological reactions, its use in river studies in the current research program was continued.

Using intuitive reasoning, additional explanation of the consistent trends (decreasing temporal variations in K_1 and increasing values of L_a) noted in the first-order reaction can be offered. It is presumed first that specific biological organisms react in a monomolecular relationship for short periods of time. Three requirements must be met for oxidation to take place: there is a reserve supply of dissolved oxygen; there is oxidizable organic matter present; and there are oxidizing bacteria, protozoa, or other predators in the waste or effluent. If these requirements are fulfilled, it can be reasoned that the microorganisms present in the organic wastes will endeavor first to adsorb and/or assimilate the most easily available food, and will be able to oxidize it fairly rapidly. Thus, the initial value of L_a represents this material, and the experienced K_1 (or k) value is high. As this food is oxidized, the population of organisms, constantly changing in numbers and species, looks to new sources of food including lower forms of organisms. The new population thereafter reaches for organic matter which is less easily oxidized and ignored in the early stages. Additions to the initial value of L_a result, and the rate of oxidation, K_1, decreases due to the difficulty with which the residual carbonaceous matter is oxidized, especially the higher level organic compounds. The anabolism and catabolism phases which exist in the metabolism of each species of organisms found in sewage or in rivers, must be included in this concept of oxidation (Busch, 1958). In a rational sense, the value of L_a should approach some asymptotic limit, and the value of K_1 (or k, base e) should sink to some minimum value, perhaps approaching zero. The results obtained in this study assist in explaining these generally known facts of biological oxidation processes. The results clearly show that final effluents have a time-average deoxygenation coefficient that is much less than that experienced in the oxidation of raw sewage.

The question which arises next concerns the ability of the first-order reaction model to predict as well as it does, considering the temporal variations observed in the BOD progression. The answer appears to lie in the compensating relationship between K_1 and L_a. The differential equation for the first-order reaction illustrates this,

$$\frac{dy}{dt} = k(L_a - y) = 2.3\ K_1(L_a - y)$$

The differential equation shows that the incremental rate of oxidation is a semblance of a product of K_1 (or k) and the amount of organic matter remaining, (L_a - y). An increase in the value of L_a compensates for a decrease in K_1, producing an apparent rate, dy/dt, which corresponds to the experimental data. However, the compensation is not perfect; thus variations as noted in this study are experienced in the time average values of K_1 and L_a as the time period is increased. The proper time period to use in applying the first-order model probably depends on the nature of the receiving stream, insofar as final effluents are concerned. Stream studies and evaluation of river values of K_1 and k may provide information as to a suitable time period for use.

The temporal changes noted in the BOD progression, as expressed in terms of K_1 and L_a, can be used in evaluating the effect of waste treatment. If the temporal changes in K_1 and L_a for raw sewage are inspected, it can be seen that the equivalency of several days BOD progression is accomplished in a few hours in the waste treatment process. Therefore, it can be hypothesized that the effluent characteristics can be approximated by entering the raw sewage temporal values and moving downward to the 4th or 5th days (or some other day) and predicting the K_1 for the final effluent as the K_1 value existing for the raw sewage at that time. Similarly, the final effluent value of L_a might be approximated as the difference between the L_a value at the 4th or 5th day and the value of the ultimate L_a for a longer period. This technique, a rough approximation, does assist in showing the accomplishments of the waste treatment process.

The results of this study of final effluents and related raw sewage characteristics will be used in subsequent studies of the stream environment and of the behavior of the river in receiving, transporting, and assimilating waste discharges. The BOD and nitrogen studies have indicated the changes in waste characteristics which take place in the treatment process. These characteristics of final effluents, and the associated volume of effluent discharge, become the inputs for the stream response. The fate of these potential pollutants will be studied and reported in the next chapter of this stream water quality study.

XII. STREAM STUDIES OF THE SKUNK RIVER AT AMES, IOWA

A. General

This phase of the research program was allocated to a study of the stream environment. Field studies of the Skunk River were conducted to determine the magnitude and relative importance of the several potential pollutants identified (1) in the laboratory experiments and (2) in other river studies reviewed in previous chapters. The variables considered to be the most important were the time of travel relationships, dissolved oxygen levels, oxidation of organic compounds in effluents, and nutrient levels. Evaluation of these variables was necessary for the development of a mathematical model for describing the response of the stream.

The hydrologic studies indicated that the natural low-flow characteristics of the Skunk River at Ames were poor, and frequently the effluent discharged by the Ames water pollution control plant was the major or entire contribution of streamflow in the reach below the city. For this reason, and related budget and manpower limitations, the field water quality studies were conducted principally in the reach of the river from Ames to Colfax, Iowa. Initial field investigations identified this section of the river as the assimilative reach for all practical purposes. However, several analyses were made at one station each on Squaw Creek and on the Skunk River upstream of Ames. These analyses provided background values of stream water quality before the occurrence of any potential urban influence at Ames.

The results of stream studies made during summer, fall, and winter periods (1966-67) are reported herein. Streamflow varied from a daily maximum of 5,520 cfs to zero flow during January to March 1967. This provided an excellent opportunity to study the stream under various flow conditions. In addition, the Ames water pollution control plant was operated in conjunction with the requirements of the research program. During two study periods a decreased level of secondary treatment was obtained by flooding the trickling filters. This decreased the plant efficiency and permitted discharging greater concentrations of BOD, ammonia and nutrients to the stream. The response of the stream environment to the increased waste loads provided the first indication of the maximum dependence which might be put on the stream for assimilative purposes, and how the stream would behave during low-flow periods.

The time of travel studies in which a fluorescent dye was used for water tracing are discussed first. The routine water quality sampling program is outlined in the next section. The special studies conducted for determining dissolved oxygen (DO) profiles are included in the third section of this chapter. Several water quality relationships developed for use in a mathematical model for water quality are presented in the fourth section. The last section includes a brief discussion and summary of water quality data collection and analysis.

The field water quality studies included some cooperative research efforts relating to algae that was coordinated with the Department of Botany. Shobe (1967) has reported on this phase, a study of the diatom communities in the stream reach downstream of Ames. Other fresh water forms of algae were not included in this study, although large growths of attached varieties were observed in the assimilative reach during low water periods. Because of the time and effort required for analysis of DO, BOD and nutrient levels, monitoring of coliform levels was not attempted and the related health aspects were not included in the study. Completion of coliform level studies and additional algae studies are suggested as future research projects to add to the knowledge of the stream environment.

B. Time of Travel Studies for the Skunk River

1. Study methods

The relationship between temporal and spatial aspects of water quality can be established only if time of travel studies are conducted for the specific stream being surveyed. Use of the mathematical models described in the literature normally rely upon time as the independent variable in forecasting the fate of pollutants in the stream. However, spatial identification of water quality in the longitudinal direction is equally or more important. Accordingly, the time of travel of potential pollutants or solutes in the Skunk River downstream of Ames was studied using a fluorescent dye as a tracer. No studies of time of travel using dye tracers had been reported in Iowa prior to this study, especially for the interior streams of this size. Therefore, the objective of the field studies included the development and evaluation of tracer techniques in addition to obtaining research results needed in the water quality research program. Three separate studies of travel times were made, at moderate, low and very low magnitudes of discharge.

The 30-mi reach of the Skunk River between Ames and Colfax was selected for study, as indicated previously. Initial water quality field studies conducted during a period of above normal discharge indicated that the Ames effluent should have little impact downstream of Colfax, at least for the summer period. Dissolved oxygen levels were always high in the downstream section of this reach.

The equipment and field study arrangements will be discussed first. A description of the operation and experimental methods will be presented next, followed by the results of the experimental tests. Additional computer analysis of the concentration hydrographs to develop time of travel or average stream velocity relationships with discharge will be considered as the fourth item, and general techniques including dye injection requirements will be discussed in the final section.

2. Equipment, supplies and general field techniques

a. Selection of Rhodamine BA dye as a tracer   A 100-lb supply of Rhodamine BA dye was purchased for the study (DuPont, $1.94 per lb in 1966). This dye is delivered in a 40% concentration in an acetic acid and methyl alcohol solution, with a specific gravity of 1.03 at 20 deg C.

The advantages of dye tracers and techniques of use have been summarized by Wilson (1968). The fluorescent dyes are excellent for tracing purposes because of five characteristics. They are: (1) water soluble, (2) easily detectable because of strong fluorescence and low background levels, (3) harmless in the concentrations normally used in stream studies, (4) relatively inexpensive, and (5) reasonably stable in the normal stream environment. Rhodamine BA has the disadvantage of having a moderate sorptive capacity and a moderate rate of photochemical decay. Rhodamine WT and Pontacyl Brilliant Pink B are listed by Wilson as being more favorable dyes, but at 2 to 7 times the cost.

The fluorescent dyes have not harmed fish life even at high concentrations, and commercial manufacturers reportedly have not had employees suffer any ill effects from skin surface contact when handling concentrated as well as dilute solutions (Wilson, 1968). However, biological effects including ingestion are of concern, and in areas where water intakes are located, concentrations at the point of intake should be limited to 10 parts per billion (ppb) or less.

b. Fluorometer equipment and use In the dilute solutions used in stream studies, fluorescence is in direct proportion to the dye concentration. This simplifies construction, calibration, and use of the commercial fluorometers now available from equipment suppliers. A Turner Model 110 Fluorometer was used in conducting the dye tracer studies.

The fluorometer operates on the principle that a material can absorb light of a certain wavelength and give off energy in the form of light having a longer wavelength. Fluorescent compounds such as Rhodamine BA convert ultraviolet light to visible light. The intensity of this visible light is directly proportional to the concentration of the fluorescent compound. The upper limit of the concentrations which can be determined is set by the absorption of the incident ultraviolet light by the dye, called the quenching effect, which causes a deviation from linearity. The quenching effect purportedly occurs frequently above 1 ppm concentration. The lower limit of concentrations which can be detected is set by the fluorescence of the solvent, or river water in tracing studies.

The operation of the fluorometer is based on an optical bridge which measures the difference between the light emitted by the sample and that emitted from a calibrated rear light path. Ultraviolet light of low intensity is passed through a primary filter which passes only UV light, and falls incident on the fluorescent sample. The reflected visible light passes through a secondary filter which filters out all UV light. The visible light strikes a very sensitive photomultiplier in a detector circuit. The detector drives an amplifier connected to a null meter. The fluorescence dial of the fluorometer is rotated by the operator until the light emitted from the sample is equal to the light from the calibrated rear light path. The rear light path is calibrated when the blank sample is set at zero with the blank knob.

The choice of the activating wavelength and the wavelength measured can affect the sensitivity of the fluorometer and the fluorescence of the blank. The Model 110 Turner Fluorometer has a primary filter admitting UV light to the sample and a secondary filter admitting only visible light of a certain wavelength to reach the photomultiplier. A primary filter of 546 mu is normally used with Rhodamine BA solutions. Because this particular filter was not available, the Model 110 filters of 814(1-60) and 822(58) categories were combined to form a narrow pass filter at 546 mu. The 110-820(25) secondary filter was used which gives a peak at 595 mu. At the wavelength used with the Rhodamine BA solutions, no secondary fluorescence was observed. Both distilled and river water gave zero fluorescence.

The fluorometer can be used to read a wide range of concentrations. This is made possible by the different sensitivity settings of X, 3X, 10X, and 30X incorporated into the device. The X setting is the least sensitive and used with high concentrations, and the 30X setting provides a sensitivity 30 times as great. The operation is quite simple. The blank dial is adjusted first until the background sample containing no dye gives a zero reading on the meter. The fluorescence dial must be at zero at this point. The unknown sample of dye solution (or river sample) is then inserted into the sample holder. The highest sensitivity is selected that can be read with the 100 divisions on the fluorescence dial. Calibration curves developed previously for known concentrations are used to give the dye concentration in parts per billion.

Calibration curves were derived from standard solutions prepared in the laboratory. It was found that linearity could be maintained for concentrations in the range of 0.5 ppb to 2,400 ppb. Higher concentrations were not investigated. In conducting the field studies, it was found that the reading of the fluorescence dial must be made immediately after insertion of the sample. Although the incoming UV light is of low intensity, at the higher sensitivities enough UV light is admitted to lower the fluorescence appreciably. In addition, as much as a 2% reduction in fluorescence may be observed for every degree Centigrade temperature rise, according to the operation manual. The ability to maintain a low temperature in the sample compartment is a feature of this specific instrument, but it was found in the field studies that appreciable drift occurs after 30 seconds.

Approximately 2 gross of small-diameter, tall glass tubes with screw caps were obtained for river sampling purposes. These were about 1/2 in. in diameter and 6 in. in length. Each was etched with an identifying number. Carrying racks were also obtained to facilitate collection and transport of the field samples.

c. Initial determination of amount of dye to be injected A preliminary estimate was made of the amount of dye tracer needed for the river studies. This was based on a modification of Eq. 8. For a concentration of 10 ppb in a flow of 100 cfs, based on dilution in 1 day's flow volume, the amount of 40% dye needed is computed to be

$$\frac{10 \times 100 \times 86,400 \times 62.4}{0.4 \times 10^9} = 13.5 \text{ lb}$$

which is equivalent to 1.57 gal per 100 cfs or 1 gal per 60 to 70 cfs. Obviously, if this amount of dye is injected at a single point the concentration will exceed 10 ppb before it is diluted or dispersed in the longitudinal direction. However, initial field inspections had indicated that the only downstream community with an auxiliary water intake was Oskaloosa, which was more than 1 day of travel time downstream. Also, studies were normally conducted in the middle of the week to avoid interference with any weekend fishing enthusiasts at bridge sites.

A preliminary field test was made on the amount of dye required to check the preliminary computations and obtain an initial estimate of the rate of movement and dispersion effect. Approximately 0.8 gal of dye solution was injected in the middle of the 30-mi study reach, at mile point 12.97 (referenced downstream from the U.S.G.S. gaging station below the confluence of Squaw Creek and the Skunk River; see Fig. 9). Although stream mileages are normally measured in an upstream direction (Water Resources Council, 1968), for the purposes of the stream water quality studies the downstream direction was selected as being more appropriate and meaningful. Mile point 0.0 was assigned to the gaging station location. Inspection of the stage and rating curve, with adjustments for the increase in drainage area, indicated that the discharge was in the range of 60 to 80 cfs. Samples were taken at two downstream points, 1.2 and 2.6 mi downstream. Peak dye concentrations were 196 and 83 ppb, respectively, for the two stations. This provided an initial confirmation that 1 gal per 100 cfs would be adequate for the first test period, and that the peak concentration would decrease rapidly with distance to the 10 ppb maximum desired at the end of the study reach.

This initial run indicated a travel time or average stream velocity of about 0.9 mi per hr for the peak concentration. It was determined from this result that the 30-mi reach should be subdivided into three reaches to permit completing a test run in a reasonable period of operation, 12 to 24 hr. Three stream reaches of almost equal length were selected and associated injection points established for the first test period.

d. Arrangements and procedures for dye tracer studies Sampling crews for the field studies were recruited from personnel of the sanitary engineering section, hourly employees, and from the staff and operating personnel of the Ames water pollution control plant. A crew of three with one vehicle was assigned to each reach. This arrangement permitted one person to be sampling the peak dye concentration period at one station, a second person observing the arrival of the dye cloud at the next downstream station, and the third member to sample previous stations for recession samples and deliver samples periodically to the receiving station or laboratory. The fluorometer was set up and operated at the Ames water pollution control plant. A laboratory technician was assigned full time to the determination of dye concentrations. Some additional assistance was obtained from laboratory personnel of the water pollution control plant in preparing samples for analysis and in washing and cleaning sample tubes.

In the second and third time-of-travel test periods, the field crews were reduced in size to two each with one additional person assigned to traverse the river network collecting sample tubes and racks, and coordinating the general operation. Arrangements were made during the first two test periods for the U.S. Geological Survey (Fort Dodge sub-district, Iowa City district) to make stream discharge measurements in the study reach the day of sampling. This provided quantitative measurements of the increase in stream discharge in the downstream direction which consistently had been observed in water quality monitoring studies.

3. <u>Summary of field operations during the three test periods</u>

a. <u>Field operation procedures</u> The dye was injected in the morning of each test period permitting the field work to be completed in a 12-hr period. However, some periods of sample collection had to be continued for up to 18 to 24 hr to complete the runs. The dye was distributed from gallon-size storage jugs by wading across the stream in a slightly downstream direction in a riffle section. This simulated a line source injection across the stream.

Samples were obtained at the center of the flowing water portion of the stream in riffle sections, avoiding deep pools of stagnant water in low water periods. Based on the estimated travel time of the leading edge of the dye cloud, samples were taken at 10- to 15-min intervals beginning approximately 30 min prior to the estimated time of arrival of the dye cloud. At the sampling stations nearest the injection point, samples were taken almost every minute as the dye cloud arrived at the station. As soon as the water cleared somewhat, samples were taken at 5-min intervals and then extended to 15- and 30-min and 1-hr intervals to provide recession data for the concentration hydrographs. At sampling stations located in the center or downstream end of each reach, the 5-min sampling intervals at the time of the peak concentration period were sufficient. Approximately 15 to 25 samples were obtained at each sampling station.

Special field data sheets were developed for the field sampling crews. Duplicate columns with common headings were used, permitting one section to be sent back to the laboratory with the collected samples and the other section to be retained for continued field reference use. This enabled the laboratory personnel to record all data from one sampling station on one page of the lab data book and provided a means of following closely the results of the sampling sequence at each station. Meanwhile the field personnel retained a record of the time and number of samples taken and could make better decisions concerning the sampling intervals. The field data sheets provided space for location of the sampling station, initial injection station and time, the time the sample was taken, number of the sample tube, and comments.

Because of the shallowness of the stream during low-flow periods, the samples were obtained by wading. The sample tubes were rinsed with stream water just prior to obtaining a sample. The technique for filling the tubes which was most successful was to insert the tube with the sampler's thumb over the opening, then in a gentle but sweeping motion move the tube to the bottom of the channel, release the thumb and fill the tube in an upward sweep to the surface. Proper timing assured that the tube was filled just prior to reaching the water surface. Samples were then recorded and stored in the racks obtained for collection purposes. The racks were kept shaded and returned to the laboratory as soon as possible. All samples were analyzed within a few hours of collection.

Three aerial flights were made during the first dye tracer study. This provided an excellent opportunity to observe the injection and initial movement and dispersion of the dye. Color photographs were obtained during the morning and afternoon flights. Only a faint pink trace was observed in the afternoon flight, compared to the relatively deep maroon color that occurred upon initial injection. The last flight was made in the late afternoon just before dusk, and the stream appeared perfectly clear from the air.

b. Discharge measurements The several discharge measurements that were made during the three test periods are listed in Table 75.

Table 75. Discharge measurements during three dye tracer study periods, Skunk River

Date	Location	Mile	Discharge, cfs
July 28, 1966	U.S.G.S. gaging station, below Squaw Creek	0.0	37.7[a]
	Below outfall from Ames WPCP	0.37	42.5
	County bridge SE of Cambridge	9.82	67.[a]
	Iowa #117 at Colfax	31.9	125.[a]
August 16, 1966	U.S.G.S. gaging station, below Squaw Creek	0.0	8.8[a]
	Below outfall from Ames WPCP	0.37	13.8
	County bridge SE of Cambridge	9.82	33.1[a]
October 8, 1966	U.S.G.S. gaging station, below Squaw Creek	0.0	0.2
	Below outfall from Ames WPCP	0.37	5.3
	Iowa #210 at Cambridge	11.0	12.2

[a]Measurement by U.S.G.S.

The waste discharge rates from the Ames water pollution control plant have also been added, at mile point 0.37. A substantial increase in discharge in the downstream direction is noted. The increase in drainage area in the study reach is only 35 to 40%, but the discharge increases much more than this. Field observations indicated that all of the tributary streams were dry after about August 1, so that the increase in discharge had to be attributed to groundwater recharge from the broad alluvial valley. The effect of the increased discharge was to dilute further the dye cloud, thus adding to the dispersion effect in reducing the peak dye concentration at downstream points.

The discharge measurements provided the first indication also of the related dilution effect which might be expected in the discharge, transport, and assimilation of effluents from the Ames water pollution control plant. The increase in base flow in the downstream direction will provide added dilution water for every mile of transport. This will increase the assimilative capacity of the stream compared to a constant discharge. The field results indicated that this phenomena, of above average influence for the reach of stream studied, should be included in developing a mathematical model of stream behavior.

c. <u>First test period, July 28, 1966</u> Injection points were established at mile points 0.0, 8.94, and 17.6, downstream of Ames and referenced to the U.S.G.S. gaging station below the confluence of Squaw Creek and Skunk River. Dye volumes injected were 3/4, 1 and 1-1/4 gal of the 40% Rhodamine BA dye. Sampling stations in the downstream direction were located at bridge sites and intermediate points. The mile points were 0.37, 1.80, 2.93, 5.34, 6.49, 8.94, 9.82, 11.0, 13.0, 14.2, 15.6, 17.6, 19.6, 22.8 and 24.7. The numbers of personnel involved in this first study were: 1 supervisor, 1 field sample collector for the entire reach, 3 field crews (2 of 3 men each, 1 of 2 men), and 1 laboratory technician, for a total of 11. Five vehicles were required. In addition, one of the university planes, pilot, and photographer were used during the day to make three aerial-survey flights. This indicates that the personnel requirements are substantial for this type of water quality research work.

The initial movement and dispersion of the dye cloud was clearly observed from the air, with the dye appearing as a sharp, deep maroon color. The initial injection was observed at mile point 0.0 and followed downstream for 1/2 hr. Both downstream injection points were surveyed next, which provided additional observation of the rapid dispersion of the dye clouds which was being experienced. The upstream reach was again observed at the end of the morning flight. The dye clouds had progressed over a mile in this period, with the distance between leading and trailing edge being about 1/4 mi in length. By the time of the afternoon flight, the dye clouds were dispersed over a length of several miles and only a pink color remained. The late afternoon flight was approximately 10 hr after the injection time, and the water was clear in all reaches. Since the laboratory results showed that there was no visual evidence of the dye below a concentration of 10 ppb, the test showed that the initial concentration was reduced to a safe drinking level after no more than 1/2 day.

d. Second test period, August 16, 1966 Additional water quality studies in the period between the first and second test periods showed that the primary assimilative reach for the Ames effluent was the reach from Ames to Cambridge, a distance of about 10 to 12 mi. Therefore, to reduce personnel requirements, the stream reach studied was reduced from 25 to 11 mi in length. Dye was injected at two locations, mile points 0.0 and 5.34, using 1/2 and 1 gal of dye, respectively, at each injection point. Samples were obtained at mile points 0.37, 1.80, 2.93, 5.34, 6.49, 7.60, 8.94, 9.0 and 11.0. The size of the field crew was reduced to 8, with 3-man crews in each reach, one supervisor to inspect and collect samples for delivery and the laboratory technician.

At the reduced level of discharge, the riffle-pool sequence was much more observable in the stream. The discharge and stage for the first test period were sufficiently high that there was good velocity at most sections. Bur during the second test period, the riffle sections were braided channels in many locations and pools were more evident. The dye clouds moved much slower, with the general peak concentration moving downstream at a velocity of about 1/2 mi per hr, or about one-half the rate experienced during the first test period.

e. Third test period, October 8, 1966 Continued dry weather caused the stream discharge to decrease rapidly, with only 0.2 cfs being observed as a daily flow average at the stream gaging station, mile point 0.0. Because of the trickle flow at this location, the dye was injected at the outfall of the water pollution control plant, mile point 0.37, and at two downstream points, mile points 2.93 and 6.49. Samples were obtained at mile points 1.0, 1.80, 2.93, 3.4, 4.2, 5.3, 6.5, 7.5, 9.0, 9.8 and 11.0, the reach from Ames to the highway bridge downstream of Cambridge.

The riffle-pool sequence was even more pronounced, and the dye clouds would move into a pool section, slowly disperse and eventually flow into the next riffle section. The average velocity of the peak dye concentration was only 1/3 mi per hr. The field crews were reduced to 2 men for each reach with one supervisor and one laboratory technician.

4. Results of the experimental program using dye tracers

The observed dye concentrations in the many samples collected in the field are not included herein, but are on file in a bound laboratory data book. Between 700 and 800 samples were taken. Analysis of the fluorometer results and development of concentration hydrographs are reported and discussed in this section.

a. Analysis of the concentration hydrographs The dye concentration data were plotted on cross-section paper to a large scale (1 in. = 10 min). This facilitated plotting the data and drawing the concentration hydrographs. The dye injection time was indicated by a heavy vertical line and all concentration hydrographs for each test period were placed on one long roll of paper. Vertical scales were changed as the dye concentrations decreased through dilution and dispersion. Smooth curves were drawn through the plotted points. The several concentration hydrographs were redrawn to a reduced scale and are included in Appendix B, with eight figures for the three test periods, one for each reach studied.

Four temporal parameters were selected for analysis. These were the leading edge, the peak concentration, one-half the hydrograph area (representing the time at which 50% of the material had passed the observation point), and the centroid of the concentration hydrograph. The trailing edge (or 10% of the peak concentration) is sometimes included in tracer analysis, but was not included in this study. The tremendous effect of dilution and dispersion caused the concentration hydrographs to become shallow and elongated at points downstream from the injection station. This effect made it difficult to evaluate the hydrograph tails and determine a precise end point. Therefore, the trailing edge was not sufficiently well defined to include data concerning it in the summary analysis. The long hydrograph tails or trailing edges influenced the centroid determinations to a great degree, and it was concluded that the half-area was a better representation of average stream velocity than was the centroidal value.

b. Computer analysis of the four temporal parameters A computer program, DYTRAC ANALYSIS, was developed to permit rapid computation of the selected temporal parameters, especially the half-area and centroidal values. A matrix of concentration-time values was extracted from the large plotted diagrams, using a constant time increment for each specific concentration hydrograph.

The input data were evaluated in the computer program to determine the two temporal parameters listed above, computing area increments, incremental centroid values, and summing for totals. This permitted rapid and accurate analysis of the hydrographs and determination of the four temporal parameter values at each sampling point. Input data included test period identification, number of data points, sampling station identification, initial dye arrival time (leading edge), time increment to be used, and the concentration values. The printed results included the temporal values based on the injection time as being zero, and the concentration hydrograph area values and half-area and centroid summary data.

c. Cumulative travel time for each of the three test periods
The temporal values for the four parameters describing time of travel were converted next to cumulative values from the initial station for each test period. In this operation, the end time for one reach (for a specific temporal parameter, such as leading edge, etc.) becomes the initial time for the next reach. The cumulative travel times for the three test periods are listed in Tables 76, 77, and 78. The results are plotted in Figs. 45, 46, and 47. Also included in the figures is a small diagram showing the relationship between average miles traveled and time, with the slope being the inverse of average stream velocity. Comparison of the cumulative travel time curves for a specific temporal parameter with the velocity indicator curves provides a measure of the average stream velocity.

A vertical line drawn through a specific mile point in any of the figures illustrates the temporal dispersion of the dye clouds based on injection at the initial point. At the end of the study reach, the time interval between the leading edge and the centroid value is some 10 to 12 hr. In a similar manner, a horizontal line drawn on any of the figures at a specific elapsed time of travel illustrates the spatial dispersion of a dye cloud injected at the initial point. At higher discharge levels, as indicated in Fig. 45, the spatial dispersion is

Table 76. Cumulative travel times obtained from the first dye tracer study of the Skunk River[a]

Mile point	Cumulative travel time, hours, for indicated temporal parameter: Leading edge	Peak concentration	Half area of hydrograph	Centroid value
0.0	0.0	0.0	0.0	0.0
0.37	0.28	0.38	0.42	0.52
1.8	1.93	2.14	2.23	2.35
2.9	3.25	4.10	4.74	4.99
5.3	6.17	7.50	8.33	8.86
6.5	7.37	9.17	9.80	10.10
8.9	11.33	12.50	12.73	13.04
9.8	12.16	13.52	13.94	14.17
11.0	13.48	15.04	15.68	16.25
13.0	15.43	17.67	18.48	19.02
14.0	17.27	19.54	20.51	21.13
15.6	18.74	21.02	22.63	23.11
17.6	21.34	24.25	25.10	25.47
19.6	22.65	27.00	27.78	28.21
22.8	27.14	30.92	32.48	33.14
24.7	29.34	33.75	35.48	35.77

[a]Test period of July 28, 1966; values computed from concentration hydrograph data.

much less than that occurring at lower discharges. After 18 hr of travel time, for instance, the spatial dispersion increases from about 3 mi (between leading edge and centroid values, Fig. 45) to over 5 mi (Fig. 47). The observed or estimated discharge values of the stream are also shown in the three figures.

5. Discussion of the results of the dye tracer studies

The dye concentration hydrographs included in Appendix B illustrate the effect of dispersion in the Skunk River channel downstream of Ames. The instantaneous injection of dye is dispersed rapidly in the longitudinal

Table 77. Cumulative travel times obtained from the second dye tracer study of the Skunk River[a]

Mile point	Cumulative travel time, hours, for indicated temporal parameter: Leading edge	Peak concentration	Half area of hydrograph	Centroid value
0.0	0.0	0.0	0.0	0.0
0.37	0.37	0.52	0.57	0.67
1.8	2.50	3.48	3.92	4.62
2.9	4.75	6.20	6.88	7.65
5.3	9.25	11.12	12.63	13.32
6.5	10.17	12.68	14.31	15.50
7.7	11.58	14.24	16.13	17.42
8.9	12.75	16.57	19.13	20.69
9.8	14.58	18.20	20.81	22.42
11.0	16.42	20.20	23.80	25.09

[a]Test period of August 16, 1966; values computed from concentration hydrograph data.

direction. The concentration hydrographs rapidly become flat and elongated in the downstream direction. Observation of river conditions for the three test periods showed that during the first run the depth of flow was sufficient to cover most if not all of the channel bottom, and the riffle-pool sequence was not well defined. By the date of the second test period, the depth of flow had receded sufficiently to give a braided channel appearance in many of the riffle sections, with occasional pools. At the very low stages of the third test period, there was a definite riffle-pool sequence. As a result of these observations, it is believed that dispersion during the first test period was predominantly the longitudinal dispersion usually considered in mathematical analysis of uniform and steady open channel flow. However, by the time of the third test, the dispersion phenomena was more of a

Table 78. Cumulative travel times obtained from the third dye tracer study of the Skunk River[a]

Mile point	Cumulative travel time, hours, for indicated temporal parameter: Leading edge	Peak concentration	Half area of hydrograph	Centroid value
0.37	0.0	0.0	0.0	0.0
0.98	1.40	1.73	1.93	2.13
1.80	2.92	3.73	4.23	4.71
2.90	5.73	7.64	8.90	9.54
3.25	6.56	8.76	10.33	11.09
4.30	8.06	11.06	12.90	13.98
5.34	11.55	16.06	18.06	19.12
6.49	14.07	18.89	20.90	21.94
7.70	15.97	21.38	23.87	25.23
8.94	19.13	25.63	28.97	30.68
9.82	22.30	27.84	32.48	34.14

[a]Test period of October 8, 1966; values computed from concentration hydrograph data.

riffle-pool-and-reservoir storage effect. The dye would move into a pool as if it were a reservoir, and would be temporarily stored until the reservoir contents were uniformly mixed, then outflow would commence. This was especially true of the pools preceded by a braided riffle section. Several braided channels lead into many of the pools at low-flow stages, an occurrence which distributes the dye more uniformly across the channel as it proceeds downstream.

The dilution and loss of dye through sorption processes was substantial, as examination of the concentration hydrographs illustrates. The total area of each hydrograph reduces rapidly in the downstream direction. The hydrograph areas determined and printed out with the computer program showed that the end-of-reach areas of the concentration

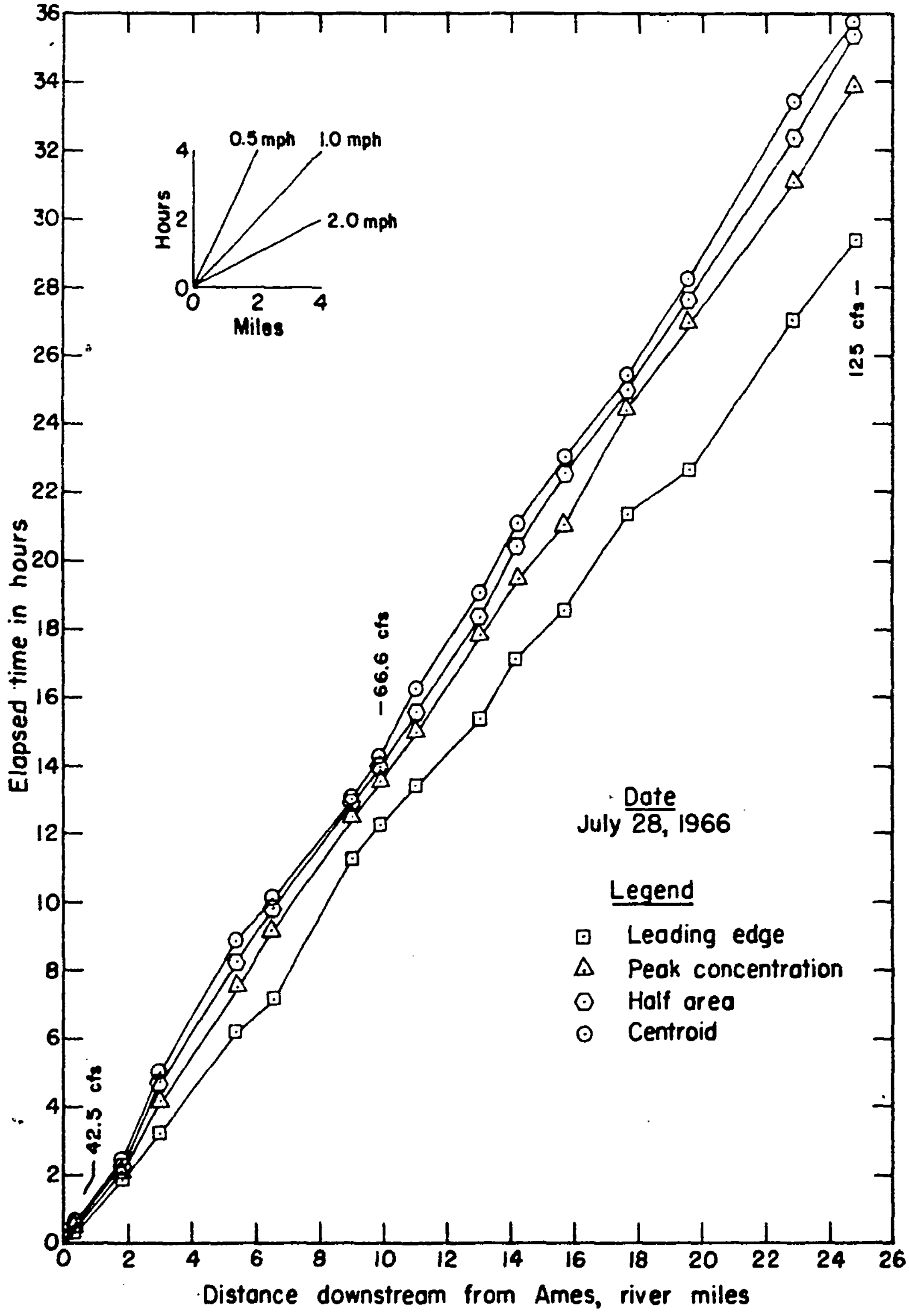

Fig. 45. Cumulative travel time for the first dye tracer study period on the Skunk River.

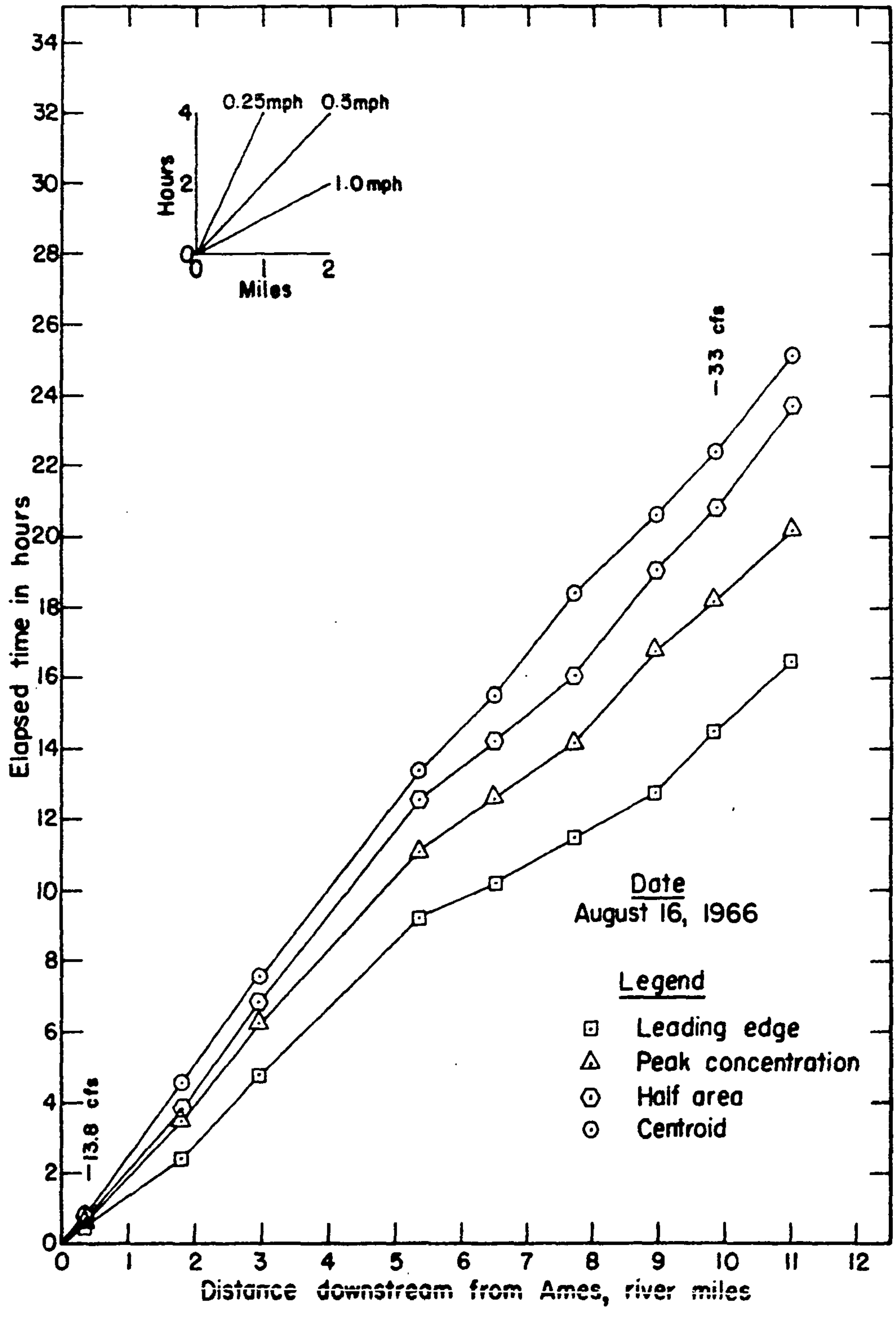

Fig. 46. Cumulative travel time for the second dye tracer study period on the Skunk River.

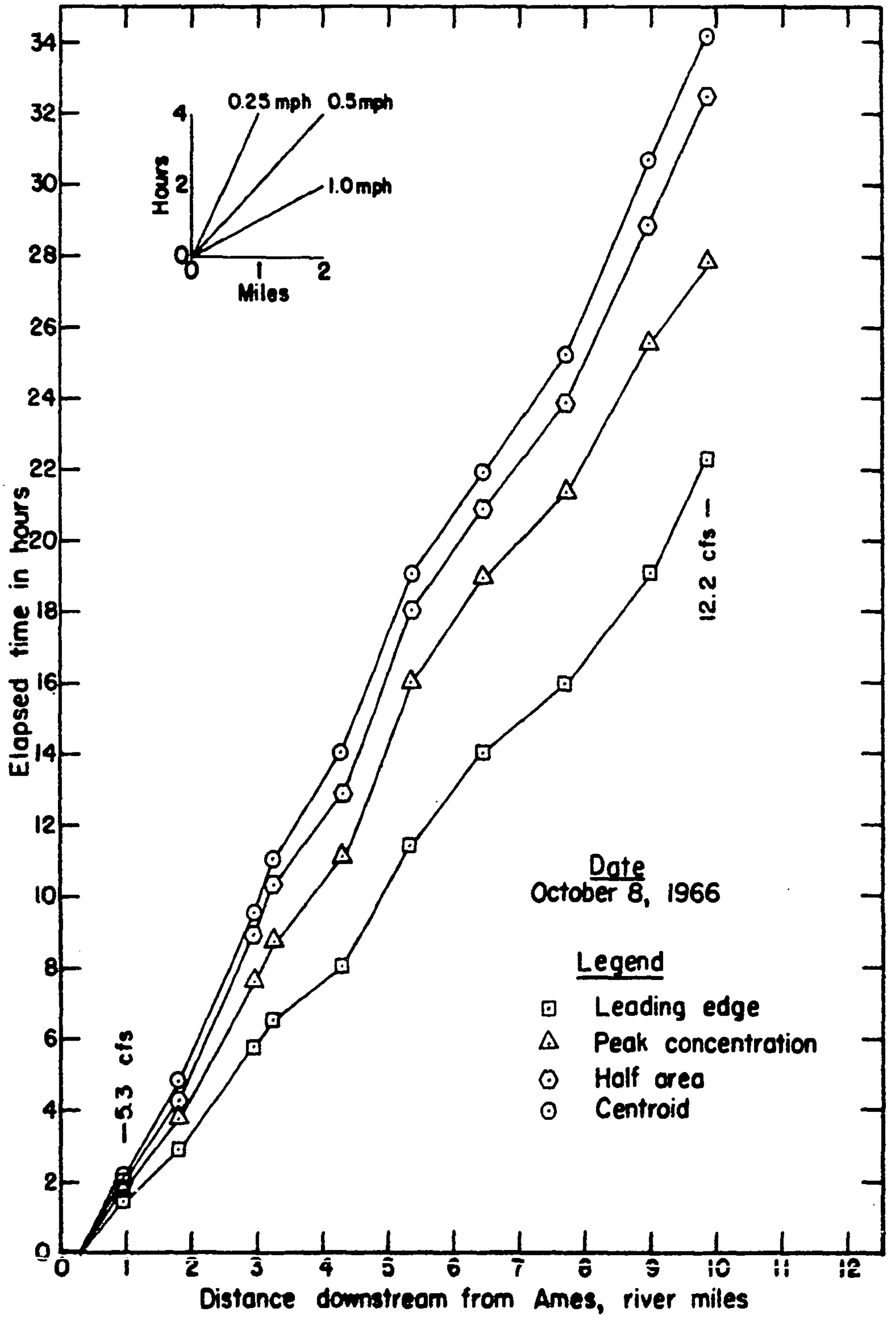

Fig. 47. Cumulative travel time for the third dye tracer study period on the Skunk River.

hydrographs would be only 2 to 10% of the area computed at the first sampling station. This means that 90 to 98% of the dye was lost through dilution and/or adsorption. Because the discharge was less than twice as great at the end of each sampling and injection reach (dilution to the 50% level), most of the loss is attributed to adsorption or absorption of the dye on the boundary, on the substantial growth of algae fixed at the boundary, or to photochemical decay in the bright sunlight. The latter effect was not analyzed independently, but it could be checked in such field studies if selected samples were exposed to sunlight at the same time the field runs were being made. Because all samples were collected and analyzed in a few hours, losses in sampling are believed to be small. However, the photochemical decay in the river under the influence of strong sunlight could be a factor in the loss of dye.

The loss of dye should not affect the time of travel results to any great degree. If the loss was uniform in time, then only the concentration hydrograph ordinates are affected, being reduced in magnitude. This would not influence the peak concentration, arrival of leading edge, or the half-area and centroid computed values. However, if the loss was predominantly in the early arrival of the material, then some error in observed values would occur. This would have the greatest effect on the computations of half-area and centroid values. In view of the many other indeterminants involved in stream water quality studies, the results obtained with the raw data were considered sufficiently accurate for the purposes of the case study. However, if dispersion effects were to be studied, the loss of dye would pose greater problems.

The use of Figs. 45, 46 and 47 in describing the dispersion phenomena was discussed above. In case of accidental spills of contaminants in the river, the figures show that the material is rapidly dispersed, both temporally and spatially. Analysis of the decrease of pollutant or dye concentration with time will be made in the following section.

6. Mathematical relationship between time of travel and discharge

Each of the three dye tracer test periods was conducted at a different level of discharge in the stream. However, the stream discharge was not constant spatially during the individual periods, but increased substantially in the downstream direction (Table 75). Inspection of Figs. 17 and 18, and of others included in Appendix A, indicate that this phenomena may be expected frequently, especially at the once-in-two year frequency level or more frequently including the average annual event. Only for the less frequent events, such as the 5-yr or 10-yr event, will the increase in discharge reach a uniform per square mile value or less. The increase in discharge complicated the attempt to relate time of travel to the discharge variable. A trial and error method of analysis was used to determine the relationship between average stream velocity and a constant discharge concept.

a. Initial analysis based on the reference discharge concept The reference discharge level for each test period was selected first. The combined flow (river and Ames WPCP effluent) downstream of the Ames water pollution control plant was selected as the reference discharge for each test period. Inspection of the time of travel curves in Figs. 45-47 indicated a somewhat uniform slope at the beginning of the study reach. This slope represents the inverse of the average velocity of the stream. The average stream velocity was used as the dependent variable in this analysis, and correlated graphically to the reference discharge. The initial plot of average stream velocity, for each of the four temporal parameters, and their relationship with the reference discharge at the beginning of the study reach, is shown in Fig. 48. The resulting relationships are curvilinear on log-log paper, and not in accordance with Eq. 9. However, the general trend of the curves in Figs. 45-47 indicates some tendency for the velocity to increase as the elapsed time increases, reflecting the influence of the increased discharge in the downstream direction as well as any variations in other stream variables. Additional analysis was next made of the effect of the increasing magnitude of discharge in the downstream direction.

b. Linearized average stream velocity versus discharge relationships The initial curves of average stream velocity shown in Fig. 48 were adjusted on a trial and error basis to reflect the increased magnitude of discharge (increasing downstream) experienced during the dye tracer studies. A curve of discharge versus mileage was constructed for each test period. Next, a linear velocity curve was simulated by superposition on Fig. 48 for each temporal parameter. The half-area relationship was used as the primary temporal parameter in this analysis. Travel time curves were then computed for each test period and for each temporal value.

The computed time of travel curves were then compared to the observed field relationships shown in Figs. 45-47. The comparison would

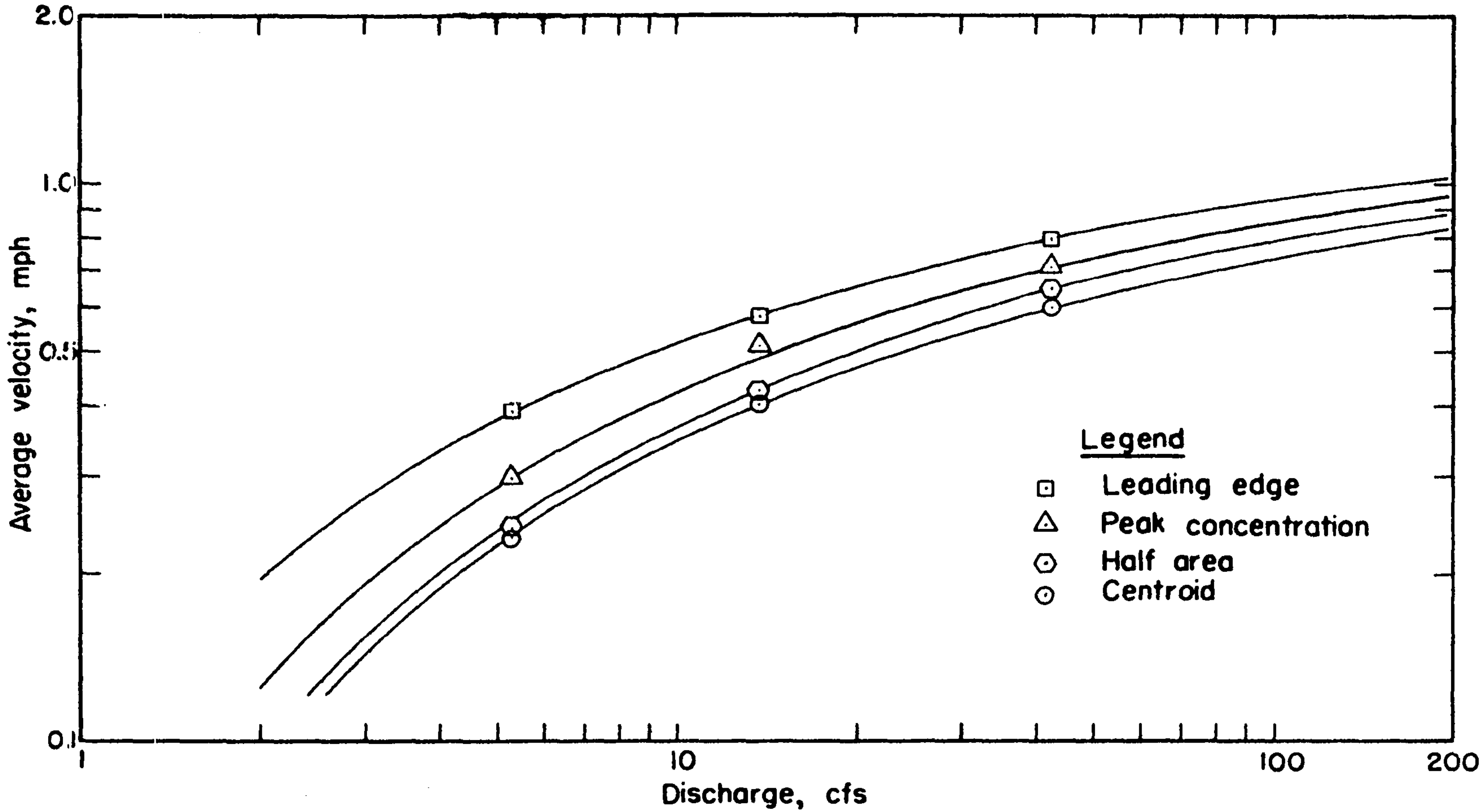

Fig. 48. Relationship between average stream velocity and discharge based on the reference discharge at the beginning of the study reach.

indicate if further adjustments were desired, and if the additional adjustment was needed at the low end of the discharge range or at the upper end. After four or five adjustments, no additional benefit was obtained by further changes.

The linearized relationships between average stream velocity and discharge for the four temporal parameters (leading edge, peak concentration, half-area and centroid) are shown in Fig. 49. The original plotted points representing the reference discharge values for each temporal parameter are also shown. These linearized relationships become the mathematical models for average stream velocity for the reach of the Skunk River being studied. For the purpose of the case study, the curves were extended to a discharge of 200 cfs. The resulting mathematical models for time of travel of solutes or effluents discharged to the Skunk River for each of the temporal parameters are:

Leading edge:

$$U = 0.246\ Q^{0.3034} \qquad (114a)$$

Peak concentration:

$$U = 0.187\ Q^{0.3432} \qquad (114b)$$

Half-area of hydrograph:

$$U = 0.149\ Q^{0.3737} \qquad (114c)$$

Centroid of concentration hydrograph:

$$U = 0.136\ Q^{0.3818} \qquad (114d)$$

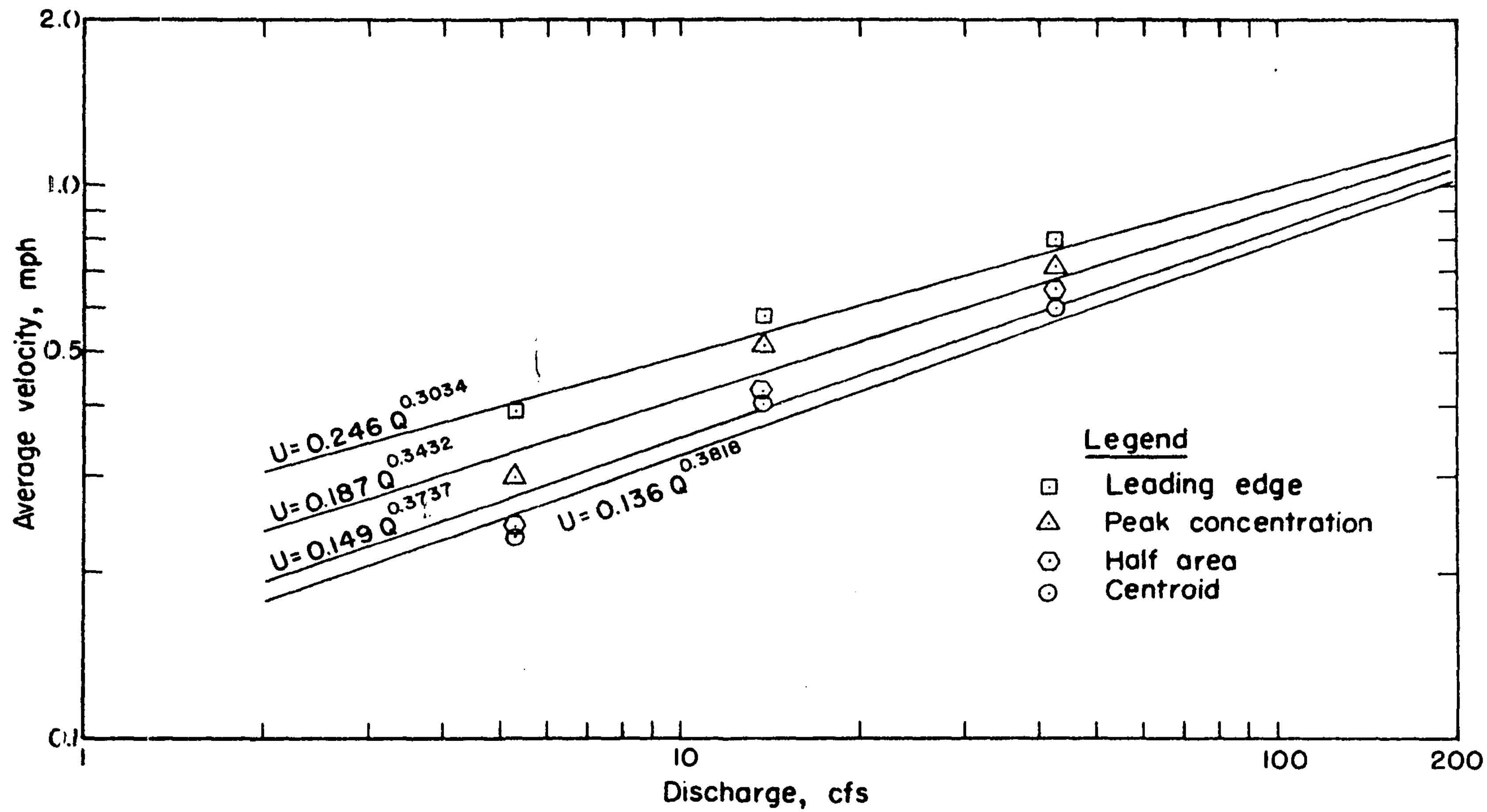

Fig. 49. Relationship between average stream velocity and discharge as linearized to a constant discharge level.

7. Analysis of injection amounts required for travel time studies

Additional analysis was made of the concentration hydrographs to determine if quantitative relationships existed among several of the parameters involved. The peak concentration of dye was selected in this analysis as the temporal parameter of primary importance in obtaining well-defined concentration hydrographs. A general review of the decrease in peak concentration with travel time was made for each reach during each test period. This included 5 reaches in the 3 test periods and the preliminary test reach of 2 mi. This review indicated some consistency among the decrease in peak concentration in the downstream direction, the observed travel time, and the amount of dye injected initially. A plot of these data was made (Fig. 50). Representative dye injection values were computed and three representative curves drawn for three dye injection rates.

Figure 50 provides a quantitative measure of the concentration level which can be achieved with Rhodamine BA dye when injected in the quantities shown. Gallons of dye injected (40% by weight) was selected as the most commonly used measure of dye amounts injected in field parlance. Gallons of dye can be converted to pounds of actual dye using the 40% by weight and 1.03 specific gravity values. Use of Fig. 50 can be made to estimate dye injection amounts for other streams in Iowa and the midwest of comparable size and having similar dispersion characteristics. To comply with the most recent safety standards (Wilson, 1968), the lower curve in Fig. 50 is suggested for use as the maximum amount of dye which should be injected, and the related maximum concentrations which should then be observed. This curve represents an injection

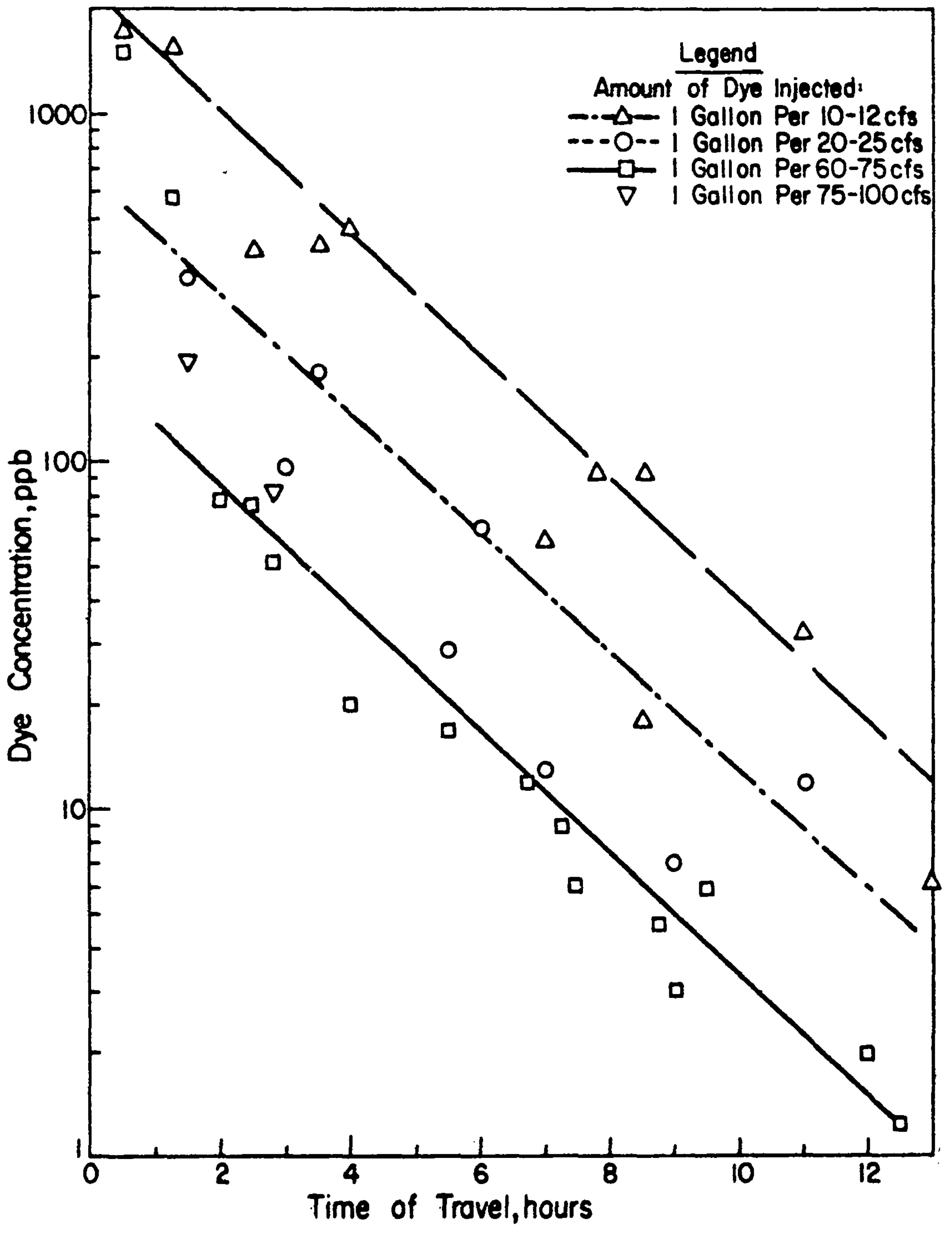

Fig. 50. Amount of dye required for injection to achieve selected concentration levels at downstream locations.

amount of 1 gal per 75 to 100 cfs. This amount would reduce to the 10 ppb concentration level after about 7 hr of travel time.

8. Summary of time of travel studies

The time of travel studies illustrate the time and effort that must be expended to obtain the temporal and spatial interrelationships illustrated in Figs. 45-50 and given in Eqs. 114a-114d. From 30 to 40 man-days of effort were required for the actual days of sampling, with some 10 additional man-days involved in preparing for the runs. An additional 20 to 30 man-days of effort were involved in the analytical evaluation and computer program work. For this expenditure of 60 to 80 man-days of effort, only 25 mi of stream were studied comprehensively, of the 280 mi included in the total length of the Skunk River.

This estimate, 2.5 to 3 man-days per mile of stream, provides an initial indication of the time and effort that will be needed if such time of travel information is to be obtained for the several major rivers in Iowa. A short-cut procedure, however, can be suggested for obtaining similar results with less field work. This would involve determining only the rate of movement of the leading edge. Dye would be injected at a known point, then the time of travel of the leading edge would be observed visually at downstream points. Bridge sites or other intermediate locations would serve as observation points, or aerial survey techniques also might be used. As soon as the dye was dispersed to the point where the leading edge was no longer visible, an additional injection would be made. Preferably, the method should be used in an upstream progression technique to avoid the influence of previous injections from interfering with subsequent injections.

This technique should be satisfactory if sample reaches were studied more intensively to develop some correlation between the rate of movement of the leading edge and other temporal parameters. The modified method should permit more streams to be studied with fewer personnel and less equipment. However, the method might require more dye in the long run, since visual observation requires higher concentrations and associated shorter reaches of stream per injection.

Whatever technique is used, the amount of dye needed to obtain a desired concentration level can be estimated using Fig. 50. The average stream velocity relationships which were obtained through these studies were used in the analysis of water quality data and in the development of a mathematical model of water quality for the Skunk River. These relationships are given as Eqs. 114a-114d for the leading edge, peak concentration, hydrograph half-area of solute passing the point of concern, and centroid of the concentration hydrograph.

C. Streamflow and Air-Water Temperature Relationships

The physical conditions of the Skunk River which prevailed during the study period will be reported in this section. These include the published stream discharge data of the U.S. Geological Survey, miscellaneous discharge measurements made during a period of high sustained base flow in the upper basin, and air and water temperature relationships.

Analysis and discussion of these physical characteristics will provide a framework for the water quality studies and analyses which follow.

1. Variations and trends of stream discharge for the period 1964-1968

The average monthly discharges of the Skunk River (below Squaw Creek), published by the U.S. Geological Survey (1968) for the period October 1964 through December 1968, are listed in Table 79 and plotted in Fig. 51. The stream discharge had receded in late 1964 to the level of 1 cfs or less, as commonly experienced in the late fall and winter periods. Zero discharge was experienced for many days in December 1964, January 1965, and early February 1965, although average daily discharges of 1 to 3 cfs were recorded at the gaging station located upstream of Ames. This loss of discharge in the reach through Ames is unique and has been the subject of additional research into the relationship of surface streamflow, groundwater levels, and city pumping rates (Sendlein and Dougal, 1968). Above normal snowfall and resultant snowmelt brought the stream to flood stages during the February through March period in 1965. Continued above-normal rainfall during the spring provided an average monthly discharge of more than 100 cfs through July. Dry summer climatic conditions resulted in streamflow recession to a daily low of 2.2 cfs in August 1965, with an average of 10.6 cfs for the month.

Precipitation was excessive throughout central Iowa in late September and October 1965, providing a higher than normal base flow for the entire winter period. The 30-day minimum low flow for the winter period, as determined in the frequency analysis of the

Table 79. Monthly discharge of Skunk River below Squaw Creek for period January 1964 through December 1968[a]

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Average monthly discharge, cfs											
1964	2.74	11.9	22.3	106	465	317	136	12.6	7.21	1.05	2.08	0.85
1965	0.05	204	557	2037	483	652	95	10.6	689	380	196	355
1966	225	191	298	280	547	847	105	21.2	3.41	0.49	1.07	0.49
1967	1.79	0.10	13.0	13.1	6.71	1383	123	34.9	4.25	4.31	4.25	2.88
1968	1.09	221	16.2	70.8	47.9	640	214	41.3	24.2	127	96	74

[a]Source: U.S. Geological Survey (1968).

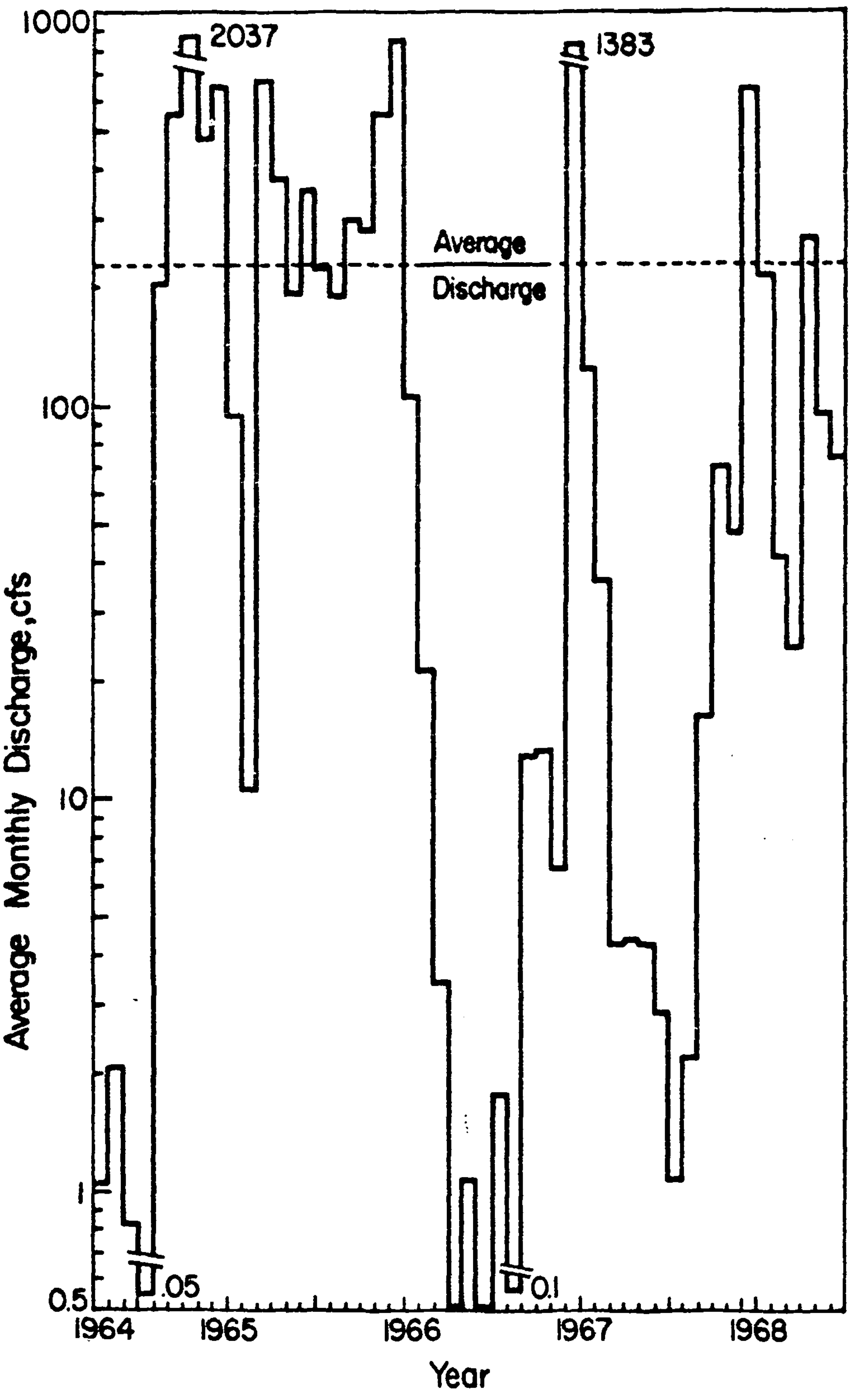

Fig. 51. Monthly discharges of the Skunk River (below Squaw Creek) for the period 1964-1968.

Skunk River flows, was 111 cfs. This was the second highest of record in the 15 yr of data collection at the site. This magnitude of discharge was considered excessive for analysis of low-flow water quality conditions. Therefore, water quality studies were delayed until the summer season of 1966.

One consistent but not necessarily normal aspect of streamflow was observed during the period 1965-1968. This was the occurrence of high flood stages each June of the 4-yr period. Peak discharges at the gaging station below Squaw Creek were reported by the U.S.G.S. to be 3,800 cfs in 1965, 6,380 cfs in 1966, 4,960 cfs in 1967, and 7,310 cfs in 1968. This provided an initial insight into the stream's flushing action and the rejuvenation process of the stream ecological environment including algal and other aquatic growths. As noted previously, stream clarity returned in a period of 8 to 14 days, with a predominantly sand bed observed in most reaches of the stream.

Except for the winter of 1965-1966, low discharge levels were recorded each year during the late fall and winter periods. The summer of 1966 was characterized by below normal rainfall, and a steady recession of the stream stage and discharge was recorded (Fig. 51). A similar but less lengthy period of streamflow recession occurred in the summer of 1967. The daily discharges for the summer and fall of 1966 are plotted in Fig. 52. Much of the field work for water quality information was accomplished during this period, and it provided an excellent opportunity to observe the stream environment and ecological habitat as the flow recession continued. The rapidity of the recession was computed from the daily discharge data shown in

Fig. 52. Daily discharges of the Skunk River during the summer and fall of 1966.

Fig. 52. The recession equation for this period was:

$$Q_t = Q_o(K_r)^t = Q_o(0.91)^t \quad (115)$$

where

Q_o = base flow of the stream at the beginning of the period,

Q_t = streamflow at the end of the period,

t = length of the low-flow recession period, in days, and

K_r = recession constant.

The observed value of 0.91 is low for Iowa streams, and indicates that low-flow conditions can occur rapidly during drought periods. This value applies to the range of discharge from 1 to 200 cfs as shown in Fig. 52.

Very low stream discharges were recorded during the winter of 1966-1967. Only in 1954 and 1956 were more severe low-flow winter periods experienced, with 60-day average discharges of 0.08 and 0.0 cfs being recorded in those years compared to 0.37 cfs in 1966-1967. As can be seen, this provided an opportunity to study stream water quality levels under circumstances when the effluent discharge from the Ames water pollution control plant was almost the entire contribution to streamflow. The low-flow measurements illustrated previously in Fig. 19 were obtained during this low-flow period, which extended through the winter period until a brief snowmelt period occurred in March 1967. Zero discharge was recorded for many days during the months of December 1966, January 1967, and February 1967. Again, discharges at the gaging station upstream of the city were in the magnitude of 1 to 3 cfs. During the following winter, 1967-1968, streamflow remained above the zero level with discharge values of 1 to 2 cfs being recorded at the lower station for most of the months of December January, and February.

2. Nonuniformity of high base flows in the upper Skunk River basin

The excessive precipitation occurring in September of 1965 resulted in high sustained base flows of all streams in the upper basin throughout the period from late September 1965 to June of 1966. In early November, during a period of mild weather, a series of discharge measurements were made in the upper basin. These were conducted as part of the research program to determine general water resources and water quality relationships in the study portion of the Skunk River basin. The results of the measurements are listed in Table 80. The computed unit area discharge values listed in Table 80 are plotted in Fig. 53. The values, ranging from 0.17 csm to 0.46 csm in the north part of the basin and with a value of 0.21 csm at Oskaloosa, indicate a substantial nonuniformity of watershed yield at high base flows. The measured values are approximately 50 to 80% of the mean flow of the streams in the basin. The trend lines included in Fig. 53 show a consistent decrease in unit area discharge for the several tributaries as the drainage area increases. Precipitation for the month of September 1965, was 11.49 in. at Webster City, 10.35 in. at Jewell, 7.23 in. at Ames, and 6.44 in. at Ankeny. The greater amounts of precipitation received in the north part of the basin account in large part for the higher unit area discharges. The discharge measurements were made at least 30 days following the storm rainfall period, and the entire

Table 80. Regional low-flow measurements in the upper Skunk River basin following a period of above normal precipitation and streamflow, November 1965[a]

Basin	Stream	General location	Drainage area, sq mi	Measured discharge, cfs	Computed unit area discharge, csm
Squaw Creek	Crooked Creek	West of Stanhope	7.0	1.84	0.263
	Squaw Creek	East of Stratford	10.2	2.22	0.217
	Squaw Creek	South of Stanhope	62.6	16.0	0.256
	Squaw Creek	NE of Ames	170.	30.8	0.181
	Squaw Creek	Ames, U.S.G.S. gaging station[b]	207	35.	0.169
Skunk River	Skunk River	East of Blairsburg	6.5	2.89	0.445
	Skunk River	SE of Blairsburg	17.3	7.87	0.455
	Skunk River	West of Ellsworth	54.9	18.98	0.344
	Mud Lake D.D. 71	NE of Jewell	64.1	19.5	0.305
	Skunk River	East of Randall	160.	50.4	0.315
	Bear Creek	SW of Roland	20.2	4.75	0.235
	Skunk River	NE of Ames, U.S.G.S. gaging station[b]	315.	100.	0.317
Skunk River	Indian Creek	Mingo, U.S.G.S. gaging station[b]	276.	45.	0.163
Skunk River	Skunk River	SE of Ames, U.S.G.S. gaging station[b]	556.	150.	0.270

[a]Field measurements using Price pygmy current meter or standard Price meter.

[b]Published data for U.S.G.S. gaging stations.

Table 80. Cont.

Basin	Stream	General location	Drainage area, sq mi	Measured discharge, cfs	Computed unit area discharge, csm
	Skunk River	SE of Cambridge	640.	154.	0.240
	Skunk River	Near Oskaloosa, U.S.G.S. gaging station[b]	1,635	350.	0.214

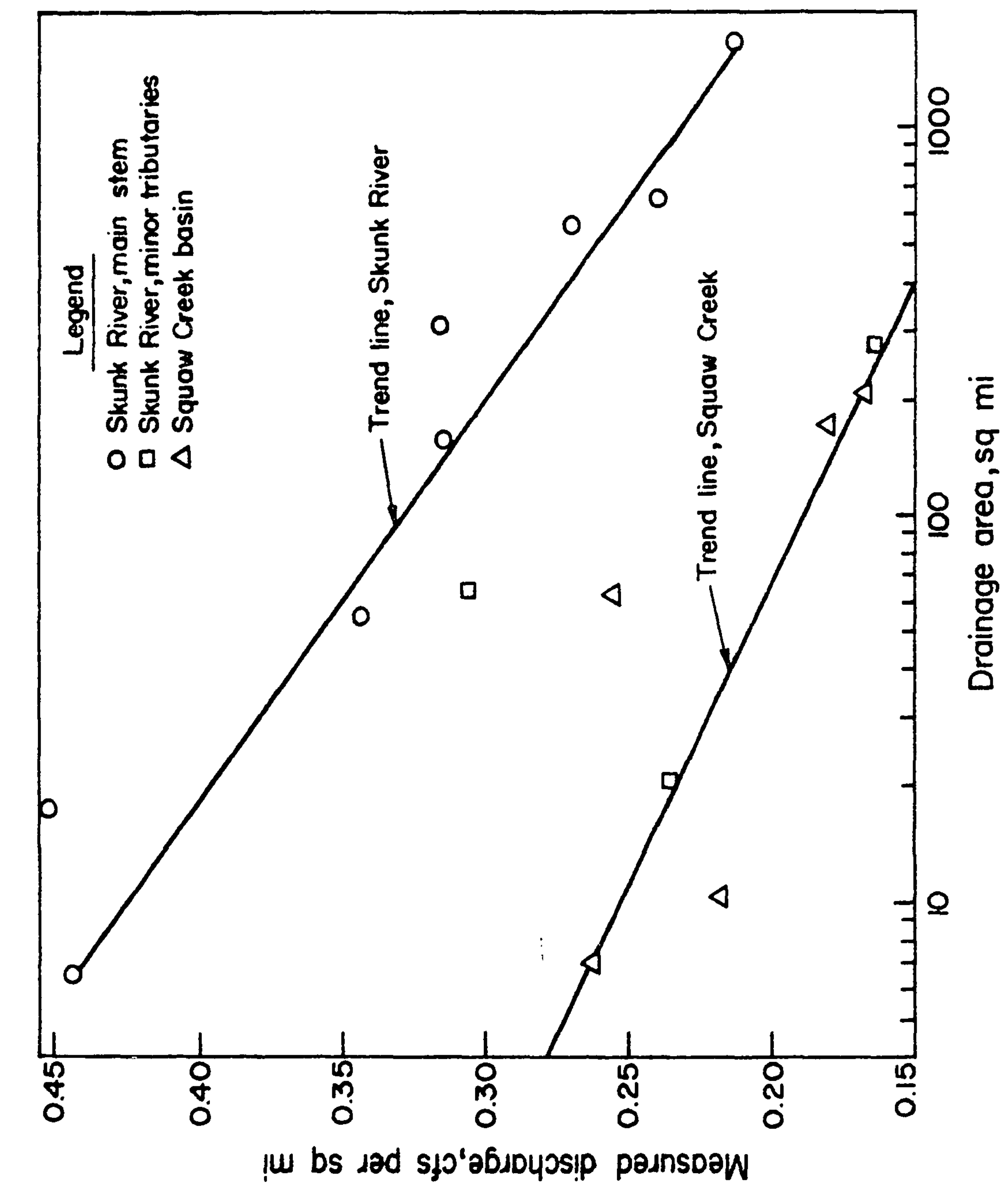

Fig. 53. Regional variations in unit area base flow contribution during November 1965.

flow was attributed to groundwater. Tile discharge in the upper basin was noted to be substantial.

The results of this study of base flows illustrate the problem of relating small-area miscellaneous discharge measurements to large-area gaging station discharges. For the period observed in 1965, more than a two-fold variation exists in tributary unit area discharge values in the north part of the basin and at points no more than 20 mi apart. During dry weather periods, the random nature of precipitation in all probability would result in equal or larger variations in the unit area discharges.

Frequently in making water quality studies in smaller tributaries, the stream discharge is not measured directly, but is estimated using a uniform unit area discharge based on the nearest gaging station on the main stream. The results of this initial series of measurements show that this may lead to substantial error, with no real alternative but the making of an actual direct or indirect discharge measurement. Although not made, a second follow-up series of discharge measurements would have been useful in evaluating the persistence of the trend established during the fall months. A brief review was made of past low-flow miscellaneous measurements made by the U.S. Geological Survey, for stations at Ellsworth, Jewell, Randall, Stanhope and Colfax as described in Table 79. During the 1957-58 period, Squaw Creek discharges were about 2 to 3 times the unit area discharges of the Skunk River tributaries upstream of Ames. During other years between 1958 and 1964 some degree of uniformity existed among the unit area discharges of the several tributaries. Therefore, it is concluded that no one part of the upper basin contributes more streamflow consistently than any other part, but that the nonuniformity which exists is random and unit area flow contributions depend primarily on the precipitation trends and variations.

3. Air and water temperature relationships

a. Installation and operation of an air and water temperature recorder A study of air and water temperatures was made during the field water quality research period. Results of this study provided the stream water temperature data needed in development and application of a mathematical model of water quality for the Skunk River at Ames, Iowa.

A continuous dual channel water and air temperature recorder was installed on a bridge pier at the Skunk River gaging station below Squaw Creek and 0.37 mi upstream of the outfall of the Ames water pollution control plant (mile point 0.0). Charts were changed weekly. Records were obtained for the period January 1, 1966 through June 12, 1968. The equipment was removed at the end of the period because of a flood, and the temperature station was not returned to service. Sufficient data concerning air and water temperatures were obtained for the purposes of the case study, during the 30-month period.

The unit was placed in a special housing secured to the downstream side of a bridge pier at midstream, and was easily accessible by a ladder installed on the pier. The water probe was placed in flowing water at the downstream edge of the pier, and was shaded from direct sunlight. The air probe presented more of a problem. For the first

6 months it was left in the instrument chamber. However, a check with maximum and minimum temperatures recorded at the water pollution control plant 1/4 mi away showed that the air probe values were dampened by the chamber unit. The air probe unit was next placed in a small shelter constructed under the bridge deck so that it would not be in direct sunlight. However, winter winds sweeping down the river and the summer problem of the bridge deck absorbing heat energy continued to give values which differed considerably from the plant air temperature data, obtained from maximum and minimum thermometers located in a standard shelter. Calibration and periodic laboratory thermometer checks indicated that the water probe was recording to ± 2 deg F. Because the air probe gave results considerably at variance with the plant results, the values were not included in the final analysis. Instead, the maximum and minimum air temperatures recorded at the water pollution control plant were included in the quantitative analysis of air and water temperatures.

b, <u>Diurnal variations of water temperature</u> The diurnal variation in water temperature as observed in the Skunk River varied from zero in the winter to as much as 20 deg F or more in hot summer weather. A typical warm weather trace for both air and water is shown in Fig. 54 for the period July 10-11, 1967. The stream discharge was about 100 cfs. During several periods in summer, water temperatures reached a level of 89 to 92 deg F, as air temperatures climbed to the 92 to 96 deg F level. This occurred even at relatively high discharges, 50 to 100 cfs, indicating the strong influence of solar energy on the stream environment.

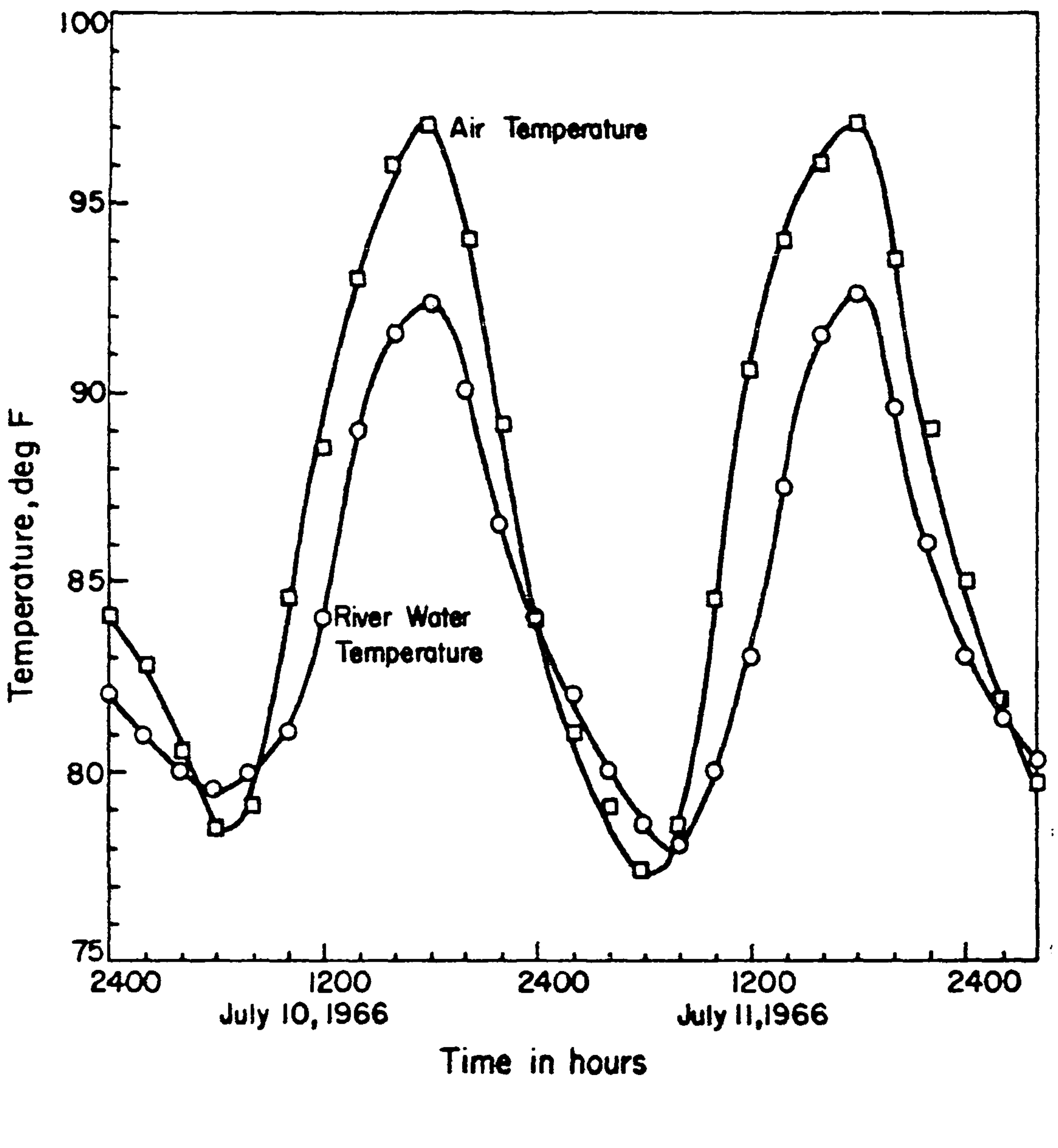

Fig. 54. A typical diurnal trace of air and water temperatures, Skunk River at Ames, Iowa.

During flood periods in summer, the water temperature normally dropped and stabilized diurnally. In some spring months, however, the opposite effect occurred, with the runoff being warmer than the base flow of the stream. Following ice breakup in the spring, water temperatures rise fairly rapidly from the 32 to 33 deg F winter level. Inspection of the diurnal temperature traces of the recorder charts indicated a close relation between air and water temperatures with the difference between maximum daily air and water values seeming to vary within a consistent range. Likewise, the relation between minimum air and water temperatures appeared to vary within a similar consistent range. Additional analysis was then made by extracting maximum and minimum daily water temperatures and relating these values to air temperature and stream discharge.

c. Analysis of air and water temperatures Both maximum and minimum air and water temperatures were obtained from the recorder charts and listed with the air temperature data of the water pollution control plant and the daily stream discharge reported by the U.S.G.S. Weekly averages of selected data were obtained using a computer program. For each year or partial year of record, the daily values were first printed out. Average weekly or 7-day values were then computed for the following parameters:

1. Weekly average of daily maximum air temperatures.
2. Weekly average of daily minimum air temperatures.
3. Weekly average of daily maximum water temperatures.
4. Weekly average of daily minimum water temperatures.
5. Weekly average of daily discharge values.

6. Weekly average of the difference between daily maximum air and water temperatures, or (1) minus (3).

7. Weekly average of the difference between daily minimum air and water temperatures, or (2) minus (4).

The results of the weekly analysis of the air and water temperature data and stream discharge are included in Appendix C. Analysis began on January 1 of each year of the study, and no attempt was made to evaluate the maximum 7-day values, etc. The weekly maximum and minimum water temperature results are plotted in Figs. 55, 56 and 57, for the years 1966, 1967, and 1968, respectively. Plots of maximum air and water temperatures, and minimum air and water temperatures, are included in Appendix C.

The plotted data show the effect of winter periods on stream water temperatures in the upper midwest as subzero air temperatures are recorded. In other studies of seasonal and annual variations of stream water temperatures (Ward, 1963; Moore, 1967), researchers have not had to contend with the subzero air temperatures and the long period of 32 deg F base temperature level of the stream in the winter period. In eastern and southern streams in the nation, annual lows of 35 to 40 deg F permit sinusoidal functions to be introduced to simulate the annual variation in stream water temperatures. This is not easily accomplished with the Skunk River data unless a partial year concept is introduced or a Fourier series concept applied. However, the data collected for the Skunk River provide a means of estimating seasonal trends and typical values can be selected for use in stream water quality studies.

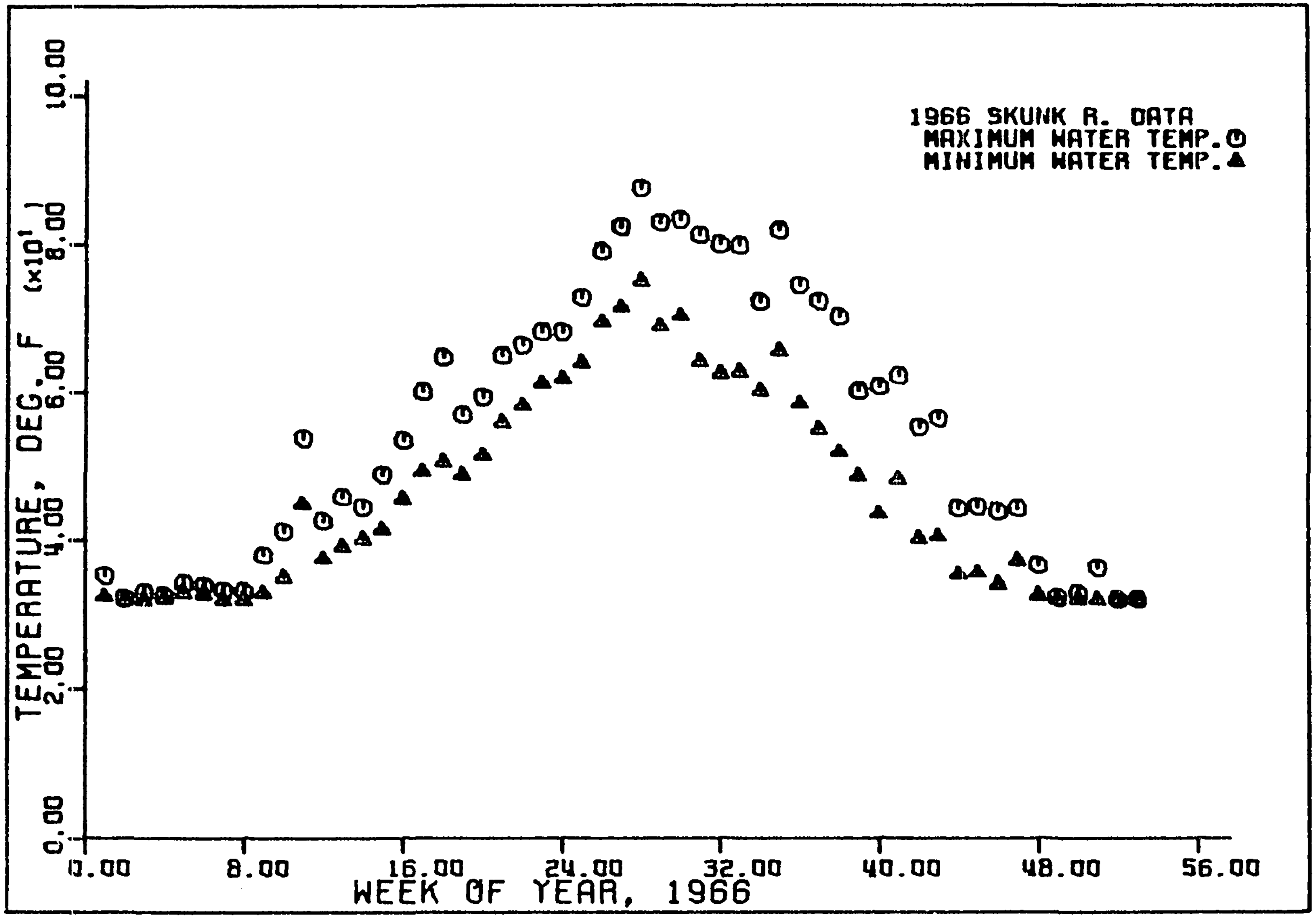

Fig. 55. Weekly maximum and minimum water temperatures of the Skunk River for 1966.

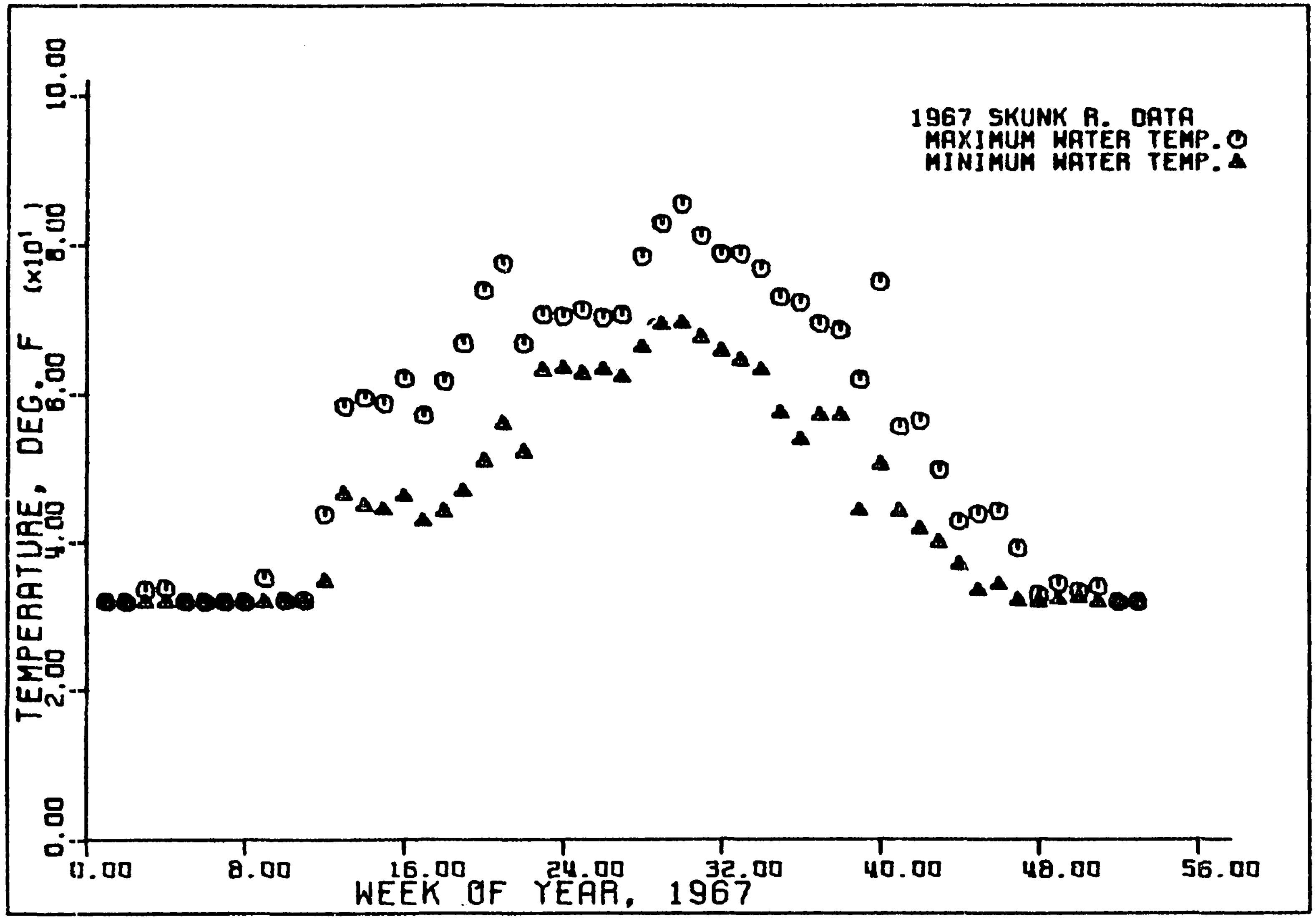

Fig. 56. Weekly maximum and minimum water temperatures of the Skunk River for 1967.

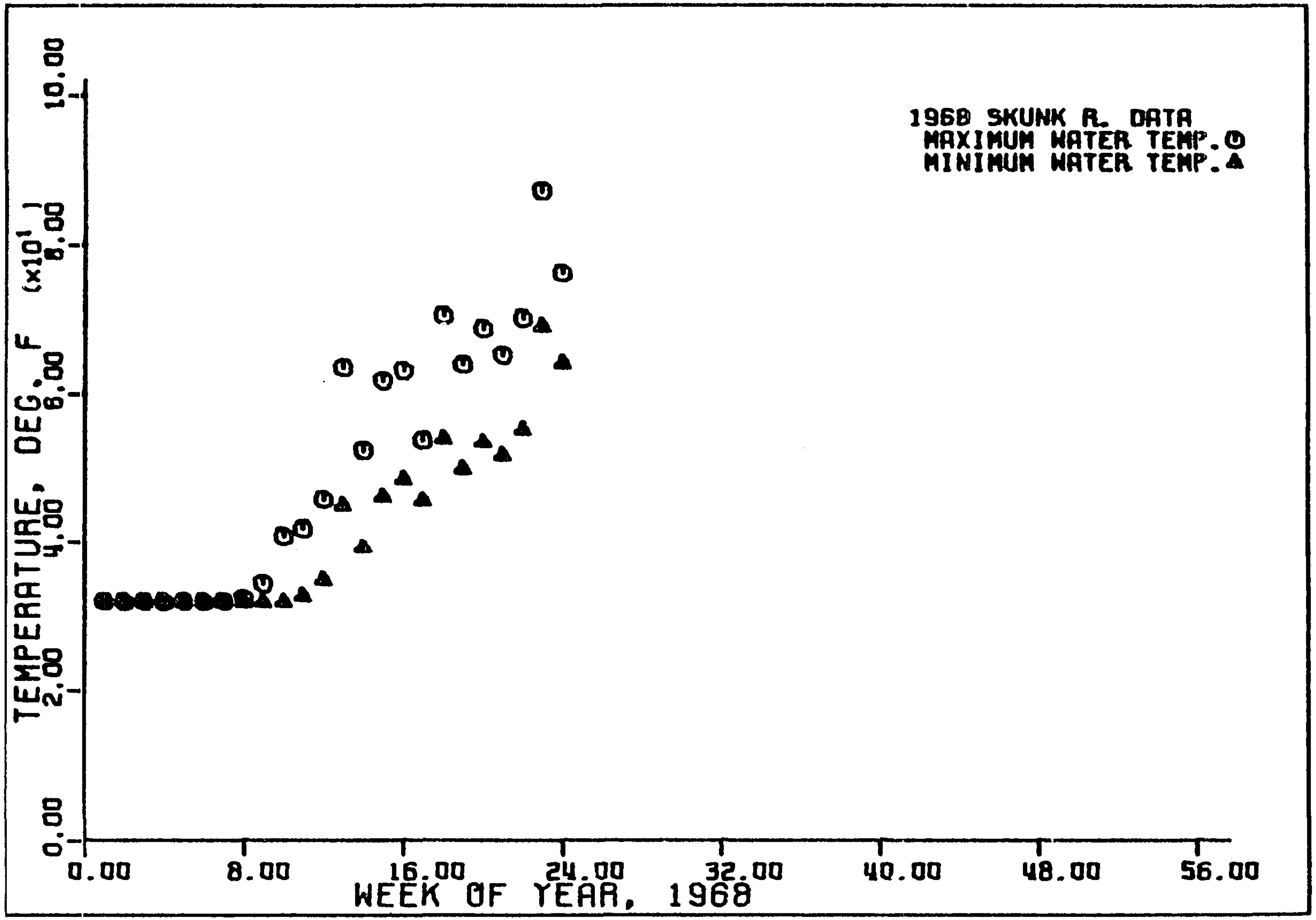

Fig. 57. Weekly maximum and minimum water temperatures of the Skunk River for early 1968.

The data for 1966 show the highest weekly average of the daily maximum water temperature, 87.4 deg F, occurring in July. A corresponding high of the weekly average of daily minimum water temperatures, 75.0 deg F, occurred at the same time. These annual highs occurred at the relatively high discharge of about 110 cfs. Air temperatures, as annual maximums, occurred the same week, with a high of 93.3 and low of 71.7 deg F. The weekly results for 1967 provided a high of 85.4 deg F for water temperatures, again in July, and with an accompanying low of 69.4 deg F. The weekly air temperature was 89.0 as a maximum value, with 61.3 deg F being the low. The average stream discharge for the week was 35 cfs. For the period January 1 through June 12, 1968, the highest weekly water temperature was 87.3; the weekly low for the same week was 69.1. Weekly air temperatures were 90.0 and 63.3 deg F for maximum and minimum values. The discharge level was 23 cfs for this week, occurring in June.

d. Discussion of results The annual trend of air and water temperatures is clearly evident from inspection of Figs. 54 through 56 and of the tabulated data and plots included in Appendix C. It is evident also that there is little direct correlation between water temperatures and stream discharge. If any effect exists, it is overshadowed completely by the effect of sunlight and solar energy. It is also evident that the maximum temperatures of both air and water do not necessarily occur at the time of minimum streamflow. This is important in water quality studies since low-flow periods normally have been of the greatest concern. Seasonal and monthly variations in water temperature must be associated with the correct seasonal or monthly low-flow values if meaningful water quality studies are to be made that simulate normal stream conditions.

The weekly variations between air and water temperatures were analyzed using the computed differences. Some rather interesting results were obtained in this analysis, as inspection of the tabulated values in Appendix C shows. Ignoring the winter months, in the spring, summer and fall seasons the maximum weekly water temperatures never lag the maximum weekly air temperatures by more than 10 to 11 deg. This observed difference appears to be seasonal, and in the summer season the difference between maximum air and water temperatures is reduced to a weekly difference of 2 to 7 deg F, with a 5 deg F difference commonly being the greatest. In general, the minimum weekly water temperatures follow a similar pattern, with the water temperatures being no more than 10 to 11 deg F above the minimum weekly air temperatures. In general, a value of 5 to 7 deg F predominates as a reasonable limit on the difference.

The results reveal that a good potential exists in the middle west region for estimating diurnal variations in water temperatures from air temperature data, at least for the smaller or shallow streams. In warm weather periods, the maximum weekly water temperature will be within 5 deg F of the maximum weekly air temperature, and the minimum weekly water temperature will be about 5 deg F greater than the weekly minimum air temperature. The maximum variations might be approximately $\pm$ 10 deg F, especially for the spring months. As winter approaches, water temperatures rapidly reach the 32 to 33 deg F level. Field observations indicated that the rapidity of ice cover development was related somewhat to stream discharge, the larger volume of water at the higher discharges requiring a longer period in which to lose the required heat energy and form an ice cover. During the fall and winter of 1965-66 with very high base flows, there were several reaches or shallow rapids where open water existed throughout the winter. With low stream stages, ice cover developed rapidly.

The water temperature results were analyzed also to provide a means of obtaining reasonable estimates of water temperatures to use in the proposed mathematical simulation model for forecasting water quality. Seasonal values for the period of study were evaluated to determine reasonable temperature values for the summer and fall months. The low-flow discharge-frequency results were used also to develop usable relationships for seasonal low flows for summer, fall and winter months. The lowest flows for summer or ice-free periods analyzed in the low-flow frequency study invariably occurred in late fall, September to November. Additional results for the summer and early fall months were evaluated to be used in combination with the seasonal temperature variations. Temperature and discharge values obtained in this analysis are summarized in Table 81. These summer, fall, and winter values were adopted for use in the proposed water quality simulation studies under future conditions of municipal waste loads and related effluent discharge to the stream system.

Table 81. Temperature and streamflow values adopted for water quality simulation studies under future conditions of municipal waste treatment

Month or season	2-yr, 7-day frequency			5-yr, 7-day frequency			10-yr, 7-day frequency		
	Water temperature deg F	River discharge		Water temperature deg F	River discharge		Water temperature deg F	River discharge	
		Base flow, cfs	Per mile increase, cfs		Base flow, cfs	Per mile increase, cfs		Base flow, cfs	Per mile increase, cfs
July	85 day 70 night	50	6.0	88 day 73 night	20.	2.5	90 day 75 night	10.0	1.2
August	82 day 67 night	25	3.0	85 day 70 night	10.	1.2	88 day 73 night	5.0	0.6
September	77 day 62 night	12.	1.5	80 day 65 night	5.	0.60	83 day 68 night	2.5	0.3
October	67 day 52 night	5.0	0.75	70 day 55 night	3.0	0.30	73 day 58 night	1.0	0.15
Winter, with ice cover	32 day 32 night	4.0	0.60	32 day 32 night	2.0	0.20	32 day 32 night	0.5	0.10

D. Water Quality Observations in Early Summer

1. Program development concepts   No published information was available at the initiation of the study concerning the movement of wastes discharged to the stream, nor of their rates of assimilation or dilution. The city of Ames made periodic checks of the dissolved oxygen at bridge sites upstream and downstream of the treatment plant outfall, but no reach-length studies had been made. Preliminary calculations and initial field observations indicated that the reach of stream between Ames and Colfax should be the reasonable extent of the potential effects of effluents on the stream water quality in the summer period. The water quality sampling network was developed for this reach.

The water quality sampling program was conducted in the reach of the Skunk River between Ames and Colfax during the summer, fall and winter of 1966-67. As noted previously, the stream at the gaging station recessed from flood stages to a zero discharge level during this period. This 30-mi section was identified during the course of the study as the assimilative reach for the Ames effluent discharge. A few water quality samples were obtained upstream of the city to provide additional background information.

Initiation of the sampling program, including equipment and techniques, will be outlined in this section. Measurements and interpretative results of the routine weekly sampling program conducted in the first part of the field study period will be included in the following sections.

2. Development of the water quality sampling program and network

a. Selection of water quality parameters Of the many important water quality parameters (McKee and Wolf, 1963), only those most relevant to the case study were selected for analysis in this study. Because municipal wastes are primarily involved, characteristics relating to such wastes were evaluated first (see Table 1). Industrial waste characteristics were not considered. Other water quality parameters indicative of a healthy stream environment were then evaluated and included (Hem, 1959; Rainwater and Thatcher, 1960; Ingram et al., 1966). The parameters relating to oxygen demand were considered to be key elements in the measurement program. Ammonia nitrogen levels were also involved, since the adopted state water quality criteria stipulates a maximum concentration in the stream of 2.0 mg/l. Some parameters were selected in cooperation with the requirements of an algae (diatoms) study made by Shobe (1967) during the research program period.

The water quality parameters selected for observation and measurement are listed in Table 82. Additional parameters were included originally in the list of desirable measurements. These included dissolved solids (or specific conductivity), coliform bacteria and volatile and suspended solids. However, the time and effort required for the other measurements precluded expanding the program to include these additional parameters. Laboratory and field analyses were made using methods listed in Standard Methods (1965). The manual published by the U.S. Geological Survey (Hem, 1959) was also helpful. The turbidity measurements were made using a Hach turbidimeter, and the semi-micro Kjeldahl method was used in determining the nitrogen levels (Bremner, 1965).

Table 82. Water quality parameters selected for observation and measurement during field studies of the Skunk River

Chemical and biochemical characteristics	Physical characteristics
1. pH	1. Temperature
2. Dissolved oxygen	2. Turbidity
3. Biochemical oxygen demand	3. General atmospheric conditions
4. Chemical oxygen demand	4. General stream conditions, color, odor, clarity
5. Alkalinity, total	
6. Hardness, total	
7. Ammonia nitrogen	
8. Organic nitrogen	
9. Nitrite-nitrate nitrogen	
10. Orthophosphate	
11. Iron	
12. Chloride	
13. Sulfate	
14. Silica	

b. Equipment and field techniques   A station wagon was equipped for use in the field; however, this type of vehicle was not dust-tight on the rural gravel roads nor was it convenient to use in the winter season. A van type vehicle is recommended although the cost is greater (Baumann and Dougal, 1968). Two laboratory field kits were constructed for use in the water sampling program. These held the required glassware and plastic containers, chemical reagents, titrating stands, etc. Two Kemmerer water samplers manufactured by Foerst, Inc. (Rainwater and Thatcher, 1960, p. 12) were used, one of 300 cc and one of 1,200 cc capacity. A portable Beckman pH meter was used to make pH measurements in the field. One gal plastic jugs were obtained for storing and transporting river samples for subsequent analysis in the laboratory. Insulated containers were used for keeping the samples cold during each sampling run.

Safety equipment required for field use included warning signs, life jackets for use during high river stages, and wading equipment for use at low water periods. Some additional equipment was obtained for use in obtaining samples through the ice in the winter season. A field first aid kit was available at all times.

At least two persons went on each sampling run, both as a safety measure and to reduce the time spent in the field collecting samples. Bridge sites were used for sampling at high river stages. During low water periods, samples were obtained by wading. The Kemmerer water samplers were used manually in the horizontal position in shallow streamflow.

Sampling in the weekly program was done in the downstream direction, beginning in the midmorning and ending in early afternoon. Samples were obtained at three cross sections of the stream at each station. Air and water temperatures, pH, alkalinity, and dissolved oxygen determinations were made in the field, using the field kits. Appropriate data sheets were made for the field research program. Appropriate notes were made concerning general atmospheric, climatic and stream conditions. The first samples obtained at each of the three sections at a station were used for immediate field determinations. The sample jugs were then filled and placed in the insulated containers. A supply of cube ice was obtained at the beginning of each run for keeping the collected samples cool until returned to the laboratory. Samples for nitrogen determination were preserved using concentrated sulfuric acid (Standard Methods, 1965).

Upon returning from a sampling run, BOD samples were set up and placed in a 20 deg C walk-in incubator. The other determinations were made the following day, except that nitrogen determinations were extended into the second or third day as necessary. BOD determinations were made for 3-, 5- and 7-day intervals to provide the basic data for evaluating L_a and K_1 (Eqs. 17 and 18).

The sampling network for the first part of the summer research period included stations at mile points 0.0, 1.80, 9.82, 19.6, and 29.0, all referenced to the stream gaging station on the Skunk River downstream of the confluence with Squaw Creek. The outfall of the water pollution control plant is located at mile 0.37. Later in the summer and fall, as the discharge of the stream receded in magnitude and the influence of the plant effluent discharge became more readily apparent, additional stations were added in the first 3 or 4 mi downstream of the outfall. During the latter part of the summer of 1966, dissolved oxygen runs were made by wading the stream from mile 2.93 to the outfall at mile 0.37. The stream is not easily accessible from the road system in this 3-mi reach, with access points only at mile points 0.38, 1.0, 1.80 and 2.93.

3. Results of the routine sampling program

a. General observations of water quality   High stream discharges in June and July of 1966 followed an early June flood period and provided excessive dilution ratios for the Ames effluent. The dilution ratio was 100:1 on June 18, but decreased to 8:1 by July 22. During this period, the stream was very clear, except during a few minor stream rises. The clean stream conditions could be considered ideal, and the results obtained during this initial period represent background water quality levels for a clean stream environment.

The results of the biochemical oxygen demand analyses for this period are listed in Table 83. Computed values of L_a and K_1 are included. These computed values were based upon daily BOD values obtained from faired curves of the plotted basic data. There was not sufficient time available for evaluating the river data for application in the modified monomolecular model developed and discussed previously. Therefore, the first-order reaction rate and ultimate BOD values were evaluated for use in the proposed stream water quality mathematical model. The computer program (BODMM) developed for evaluating the BOD constants by the method of moments was used.

Observed water quality levels during this 2-month period for the other water quality parameters are tabulated in Tables 84 through 91. For some of the runs, complete laboratory analyses for all parameters were not made, and for certain intermediate stations only temperature and dissolved oxygen data were obtained.

Inspection of the results reveals that the 5-day BOD values were below 2 mg/l through June and early July. The computed ultimate BOD values, L_a, were less than 3.2 mg/l. Because of the relatively low BOD values and inaccuracies of results at these low values, the computed laboratory K_1 values show some variation, ranging from 0.045 to 0.264. However, most of the values of K_1 are in the 0.08 to 0.11 range.

Table 83. Results of weekly BOD sampling of the Skunk River, summer period, 1966

Date	Station Bridge	Station Mile point	Discharge, cfs River	Discharge, cfs Ames WPCP	Biochemical oxygen demand for indicated day, mg/l 3	5	7	Computed BOD parameters L_a, mg/l	K, per day
June 18	SK-1	0.0	731.	7.1	0.71	1.05	1.27	1.91	0.068
	SK-3	1.80			0.73	1.60	2.78	2.09	0.119
	SK-8	9.82			0.72	1.40	1.42	2.04	0.095
	SK-14	19.6			0.96	1.45	2.52	2.27	0.086
	SK-17	29.0			0.64	1.39	2.52	1.97	0.101
June 25	SK-1	0.0	318.	5.7	1.14	1.54	2.27	2.21	0.104
	SK-3	1.80			0.62	1.30	1.24	2.04	0.086
	SK-8	9.82			1.18	1.41	2.85	1.47	0.245
	SK-14	19.6			1.23	1.77	2.30	2.33	0.084
	SK-17	29.0			1.42	1.67	3.30	1.72	0.264
July 1	SK-1	0.0	321.	6.1	0.84	1.45	2.98	3.15	0.045
	SK-3	1.80			0.95	1.50	2.47	—	—
	SK-8	9.82			1.06	1.96	3.30	2.09	0.107
	SK-14	19.6			1.25	2.04	3.31	2.35	0.113
	SK-17	29.0			1.07	1.81	2.71	2.32	0.096
July 9	SK-1	0.0	130.	5.5	1.18	1.79	3.17	2.41	0.109
	SK-3	1.80			1.58	2.42	3.58	3.87	0.081
	SK-8	9.82			1.61	3.18	4.31	4.99	0.085
	SK-14	19.6			1.47	1.92	2.89	2.21	0.162
	SK-17	29.0			1.54	2.30	2.95	4.17	0.067

Table 83. Cont.

Date	Station Bridge	Station Mile point	Discharge, cfs River	Discharge, cfs Ames WPCP	Biochemical oxygen demand for indicated day, mg/l 3	5	7	Computed BOD parameters L_a, mg/l	K, per day
July 16	SK-1	0.0	115.	5.1	2.27	2.61	3.92	2.85	0.202
	SK-3	1.80			1.60	2.48	4.16	2.74	0.187
	SK-8	9.82			2.32	2.74	3.67	2.89	0.219
	SK-14	19.6			2.41	2.92	3.02	3.05	0.240
	SK-17	29.0			2.86	3.56	4.59	3.85	0.214
July 22	SK-1	0.0	39.	5.0	1.27	1.67	2.36	2.04	0.140
	SK-3	1.80			1.50	3.15	4.95	4.10	0.122
	SK-8	9.82			1.68	2.49	4.61	3.97	0.082
	SK-14	19.6			0.99	1.30	2.12	1.69	0.124
August 3	SK-1	0.0	15.	4.6	—	1.93	2.31	2.24	0.156
	SK-2B	0.38			—	3.34	4.69	4.33	0.120
	SK-4	2.93			—	1.77	2.51	2.45	0.142
	SK-6	6.49			1.95	2.40	3.22	3.14	0.146
	SK-8	9.82			2.02	2.12	2.65	2.92	0.114
August 11	SK-1	0.0	10.	4.5	1.66	2.37	—	3.64	0.090
	SK-2B	0.38			10.40	15.80	—	—	—
	SK-4	2.93			4.84	12.25	—	22.3	0.068
	SK-6	6.49			3.16	7.70	—	13.0	0.076
	SK-8	9.82			2.70	7.41	—	12.2	0.076

Table 84. Observed water quality in the Skunk River, June 18, 1966

Parameter	Station Squaw Creek	Mile 0.0	Mile 1.80	Mile 9.82	Mile 19.6	Mile 29.0
pH	8.2	7.5	7.6	7.6	7.8	7.5
Alkalinity, total, mg/l	270.	281.	273.	262.	260.	263.
Dissolved oxygen, mg/l	8.72	9.6	8.9	8.5	8.2	8.1
Temperature, deg F	70.	67.	63.	66.	67.	68.
Ammonia nitrogen, mg/l	–	0.7	0.8	0.7	0.8	0.7
Organic nitrogen, mg/l	–	0.5	0.2	0.7	0.1	0.3
Nitrate nitrogen, mg/l	–	10.0	9.1	8.3	8.4	7.6
Total nitrogen, mg/l	–	11.2	10.1	9.7	9.3	8.6
Chemical oxygen demand, mg/l	–	22.	14.	25.	26.	26.
Discharge, cfs						
Skunk River		731.				
Ames WPCP		7.1				

Table 85. Observed water quality in the Skunk River, June 25, 1966

Parameter	Station Mile 0.0	Mile 1.80	Mile 9.82	Mile 19.6	Mile 29.0
pH	8.0	8.0	8.2	7.9	8.1
Alkalinity, total, mg/l	273.	272.	264.	267.	269.
Hardness, mg/l $CaCo_3$	400.	395.	384.	374.	366.
Dissolved oxygen, mg/l	7.9	7.4	7.3	7.2	7.4
Temperature, deg F	73.	73.	77.	78.	79.
Ammonia nitrogen, mg/l	0.4	0.6	–	0.4	0.7
Nitrate nitrogen, mg/l	9.0	8.6	–	–	6.9
Total nitrogen, mg/l	9.4	9.2	–	–	7.6
Chemical oxygen demand, mg/l	4.0	8.1	12.6	10.2	21.3
Chloride, mg/l	13.0	–	11.4	11.0	10.5
Sulfate, mg/l	105.	–	125.	–	125.
Silica, mg/l	21.	–	21.	–	25.
Discharge, cfs					
Skunk River	318.				
Ames WPCP	5.7				

Table 86. Observed water quality in the Skunk River, July 1, 1966

Parameter	Station Mile 0.0	Mile 1.80	Mile 5.34	Mile 9.82	Mile 19.6	Mile 29.0
pH	8.2	8.2	–	8.2	8.2	8.2
Alkalinity, total, mg/l	282.	280.	–	278.	277.	275.
Hardness, mg/l $CaCo_3$	390.	392.	–	–	378.	380.
Dissolved oxygen, mg/l	7.5	7.3	7.0	6.9	7.0	7.1
Temperature, deg F	78.	77.	78.	79.	81.	81.
Ammonia nitrogen, mg/l	0.34	0.4	–	–	–	0.6
Nitrate nitrogen, mg/l	9.9	9.9	–	–	–	8.2
Total nitrogen, mg/l	10.2	10.3	–	–	–	8.8
Chemical oxygen demand, mg/l	23.	21.	–	–	23.	25.
Orthophosphate, mg/l PO4	0.23	0.80	–	–	–	–
Chloride	12.4	8.2	–	–	–	10.2
Sulfate	78.	85.	–	–	–	95.
Silica	32.	32.	–	–	–	43.
Turbidity, JTU	36.	34.	–	–	–	42.
Discharge, cfs						
Skunk River	321.					
Ames WPCP	6.1					

During the period July 10 through August 11, the BOD values began to increase as the base flow of the stream continued to recede and the Ames effluent discharge became an appreciable part of the total stream discharge. Up through August 3, the water pollution control plant provided complete treatment, except for periods when the trickling filters were flooded one at a time to control filter flies. The BOD values for 3, 5, and 7 days and the L_a values all remained less than 5 mg/l during this period. Even at the minimum dilution ratio for the period, 3:1 on August 3, stream water quality levels were satisfactory. Inspection of the records of the water pollution control plant (Seidel, 1968), indicated that final effluent BOD_5 values were 30 to 40 mg/l in June, 20 to 26 mg/l in July, and 23 to

Table 87. Observed water quality in the Skunk River, July 9, 1966

Parameter	Station Mile 0.0	Mile 1.80	Mile 5.34	Mile 9.82	Mile 19.6	Mile 29.0
pH	8.3	8.1	–	8.2	8.2	8.1
Alkalinity, total, mg/l	257.	265.	–	274.	260.	274.
Hardness, mg/l $CaCo_3$	376.	379.	–	–	–	355.
Dissolved oxygen, mg/l	7.6	7.4	7.2	7.2	7.7	7.8
Temperature, deg F	76.	77.	79.	80.	81.	82.
Ammonia nitrogen, mg/l	0.6	0.6	–	–	0.7	–
Nitrate nitrogen, mg/l	4.8	4.2	–	–	2.4	–
Total nitrogen, mg/l	5.4	4.8	–	–	3.1	–
Iron, mg/l	0.25	0.30	–	–	–	0.35
Orthophosphate, mg/l PO_4	0.26	0.58	–	–	–	0.53
Chloride, mg/l	12.	13.	–	–	–	13.
Sulfate, mg/l	110.	90.	–	–	–	95.
Turbidity, JTU	17.	17.	–	–	–	23.
Discharge, cfs						
Skunk River	130.					
Ames WPCP	5.5					

25 mg/l in early August. Pasteurized samples gave BOD_5 values less than 10 mg/l during this period. The raw sewage BOD_5 varied between 100 to 150 mg/l indicating a weak sewage undoubtedly diluted by groundwater infiltration during this period of high base flow in the stream.

Treatment of the municipal sewage was reduced at the water pollution control plant on August 9, 1966. By flooding the trickling filters, a simulated primary effluent was discharged to the stream. This technique was adopted to load the stream more heavily and obtain some measure of the capability of the stream to assimilate effluents, since the initial study had indicated clean stream conditions with no real pollution problem. Therefore, the August 11, 1966 sample run

Table 88. Observed water quality in the Skunk River, July 16, 1966

Parameter	Station							
	Squaw Creek	Skunk above Ames	Mile 0.0	Mile 1.80	Mile 5.34	Mile 9.82	Mile 19.6	Mile 29.0
pH	8.1	7.9	8.3	8.1	—	8.1	8.2	8.3
Alkalinity, total, mg/l	276.	211.	227.	237.	—	224.	239.	240.
Hardness, mg/l $CaCo_3$	364.	369.	464.	654.	—	—	—	—
Dissolved oxygen, mg/l	8.5	7.9	8.3	8.2	8.5	8.4	8.8	9.8
Temperature, deg F	71.	74.	75.	76.	77.	79.	79.	79.
Ammonia nitrogen, mg/l	0.4	0.5	0.5	0.5	—	—	—	0.5
Nitrate nitrogen, mg/l	5.4	4.3	4.6	5.4	—	—	—	3.8
Total nitrogen, mg/l	5.8	4.8	5.1	5.9	—	—	—	4.3
Iron, mg/l	0.10	0.12	0.11	0.08	—	—	—	—
Orthophosphate, mg/l PO_4	0.52	0.54	0.50	1.0	—	1.4	—	—
Chloride, mg/l	10.	18.	13.	14.	—	—	—	—
Sulfate, mg/l	65.	65.	70.	83.	—	—	—	—
Silica, mg/l	26.	23.	22.	23.	—	—	—	—
Turbidity, JTU	10.	16.	10.	14.	—	22.	10.	12.
Discharge, cfs								
Skunk River	115.							
Ames WPCP	5.1							

Table 89. Observed water quality in the Skunk River, July 22, 1966

Parameter	Station Mile 0.0	Mile 1.80	Mile 5.34	Mile 9.82	Mile 19.6
pH	8.1	7.9	–	7.9	8.1
Alkalinity, total, mg/l	269.	248.	–	249.	251.
Dissolved oxygen, mg/l	10.2	9.1	10.1	9.6	9.0
Temperature, deg F	69.	70.	72.	72.	73.
Ammonia nitrogen, mg/l	0.8	0.4	–	–	0.2
Nitrate nitrogen, mg/l	2.8	2.4	–	–	1.7
Total nitrogen, mg/l	3.6	2.8	–	–	1.9
Iron, mg/l	0.15	0.09	–	–	0.13
Orthophosphate, mg/l PO_4	0.25	1.60	–	1.49	0.63
Sulfate, mg/l	140.	150.	–	130.	140.
Silica, mg/l	23.	22.	–	–	22.
Turbidity, JTU	11.	6.0	–	6.5	7.0
Discharge, cfs					
Skunk River	39.0				
Ames WPCP	5.0				

Table 90. Observed water quality in the Skunk River, August 3, 1966

Parameter	Station Mile 0.0	Mile 0.38	Mile 2.93	Mile 6.49	Mile 9.82	Mile 11.0	Mile 13.0
pH	8.1	8.0	7.9	8.0	8.1	–	–
Alkalinity, total, mg/l	232.	230.	248.	237.	236.	–	–
Hardness, mg/l $CaCo_3$	358.	–	360.	–	338.	–	–
Dissolved oxygen, mg/l	10.2	9.0	10.5	11.4	10.0	9.9	10.0
Temperature, deg F	72.	73.	75.	77.	79.	81.	82.
Ammonia nitrogen, mg/l	0.4	0.6	0.7	–	0.4	–	–
Nitrate nitrogen, mg/l	0.3	12.2	1.2	–	1.1	–	–
Total nitrogen, mg/l	0.7	12.8	1.9	–	1.5	–	–
Iron, mg/l	0.60	–	0.6	–	0.1	–	–
Chloride, mg/l	22.	–	21.	–	20.	–	–
Silica, mg/l	23.	–	23.	–	21.	–	–
Turbidity, JTU	7.7	3.8	4.2	–	3.0	–	–
Discharge, cfs							
Skunk River	15.0						
Ames WPCP	4.6						

Table 91. Observed water quality in the Skunk River, August 11, 1966

Parameter	Station Mile 0.0	Mile 0.38	Mile 2.93	Mile 6.49	Mile 9.82	Mile 11.0
pH	8.1	7.9	7.8	8.0	8.0	–
Alkalinity, total, mg/l	252.	265.	253.	250.	240.	–
Dissolved oxygen, mg/l	9.1	6.9	9.6	10.3	8.0	7.6
Temperature, deg F	70.	73.	76.	82.	82.	82.
Ammonia nitrogen, mg/l	0.0	5.4	2.6	–	–	–
Nitrate nitrogen, mg/l	0.3	0.1	0.7	–	–	–
Total nitrogen, mg/l	0.3	5.5	3.3	–	–	–
Turbidity, mg/l	9.0	2.2	3.0	3.0	2.9	–
Discharge, cfs						
Skunk River	10.0					
Ames WPCP	4.5					

brought the routine sampling to an end and a series of special studies began.

b. Discussion of observations Concentration levels for the water quality parameters listed in Tables 84 through 91 illustrate in general the clean stream condition. Dissolved oxygen values were above 7 mg/l in the daytime at all stations during this study period. No well-defined oxygen sag curve was discernible so the spatial extent of DO depression could not be evaluated.

Temperature increases in the downstream direction reflect both the small effect of the effluent discharge (with a groundwater source for the city water supply) and of the diurnal variation during the time the sampling runs were being made. The stream pH varied little, ranging from 7.5 to 8.3 with most values being above 8.0. Nitrate nitrogen levels decreased during the period at all stations until August 3, when the outfall station was added to the circuit. The decreasing levels may reflect agricultural pollution to some extent, as tile discharge contributed to the high base flow following the surface runoff and flood conditions in early June. Nitrogen values at the outfall station on August 3 indicate a well-nitrified effluent from the trickling filter secondary treatment process, with low ammonia levels and high nitrate levels. Supersaturation with DO was more apparent by late July in the daytime sample runs. This slowly increasing trend showed the general effect of the growth of algae in the stream during this recession period. Field observations indicated that the diatom community could not establish itself on the shifting sand bed of the channel at the high base flows, but gradually covered the channel bottom as the discharge and velocity decreased in magnitude. Attached forms of green algae became predominant in the reach downstream of the outfall. Water samples slowly began to show a green tinge, especially during the later fall months at even lower base flows. The effluent discharge, having a combined level of 4 to 12 mg/l nitrate nitrogen and 0.5 to 1.0 mg/l orthophosphate in the stream at the outfall, provided an abundance of nutrients for the growth of algae. Upon converting the waste treatment to primary treatment on August 9, the sampling run on the 11th gave high ammonia and low nitrate results, illustrating the loss of efficiency of the trickling filters in the flooding process.

Turbidity values remained low during this initial period of study, except for one stream rise occurring prior to July 1, which resulted in a turbid, muddy stream. DO and other field determinations were difficult to make in the turbid flood water unless sediment was allowed to settle and the supernatant used in the laboratory determinations.

4. An initial diurnal dissolved oxygen study

An initial study of the diurnal variation of dissolved oxygen and related temperature effects was made in early July at the stream gaging station. This study was made to detect any initial influence of the algal environment at the higher base flows. The results are listed in Table 92, and the dissolved oxygen values are plotted in Fig. 58. The values of DO varied from 80% of saturation at night to 110% of saturation in the daytime, showing the respiration effect at night and combined photosynthesis and respiration phase in the daytime. This was within 1 month following high flood stages which essentially swept away any previously-established ecological habitat. The stream discharge was about 100 cfs. The average DO for the day was 6.7 mg/l. The rapidity with which the DO level drops in the afternoon is illustrated in Fig. 58. The DO content dropped from 7.3 to 6.3 mg/l (above saturation to below saturation) in a 2-hr period as dusk approached.

E. A Comprehensive Series of Water Quality Studies

1. Need for special studies under controlled conditions

The routine stream sampling program conducted during the high base flow period of June and July failed to indicate any measurable effect of the Ames effluent load discharged to the stream. With dilution ratios ranging from 100:1 downward to 8:1, the stream remained at an excellent level of water quality. The stream water in general was very clear and only

Table 92. Initial diurnal study of temperature and dissolved oxygen levels, Skunk River[a]

Time, CDT	Dissolved, oxygen mg/l	Percent saturation[b]	Temperatures Water Deg C	Water Deg F	Air Deg C	Air Deg F
July 12, 1966						
0630	6.51	83	25.7	78	27.	81
0830	6.77	87	26.1	79	29.	84
1030	7.25	96	27.3	81	32.	90
1230	7.51	103	29.5	85	34.0	93
1430	7.59	108	31.5	89	34.4	94
1630	7.48	110	32.8	91	34.6	95
1830	7.35	107	32.3	90	32.5	91
2030	6.25	88	30.8	87	29.5	85
2230	6.04	83	29.5	85	28.	82
0030	6.00	81	28.6	83	28.	82
0330	6.03	80	27.3	81	26.8	80
0700	6.33	82	26.4	80	27.	81

[a]Station SK-1, mile 0.0, July 12, 1966; stream discharge, about 100 cfs.

[b]Computed as 97% of sea level saturation values.

at the edges of the stream had the boundary diatom communities established themselves sufficiently to permit visual observation. At the center of the channel (or in the small braided channels) the sand moving as bed load prevented the algae from growing across the bottom. In quiescent pools, attached forms of green algae were gradually becoming more noticeable, but the attached varieties were not in such profusion as they were later in the fall under very low streamflow conditions.

The research program was revised in August. Initial day and night dissolved oxygen field runs were made to determine the nature

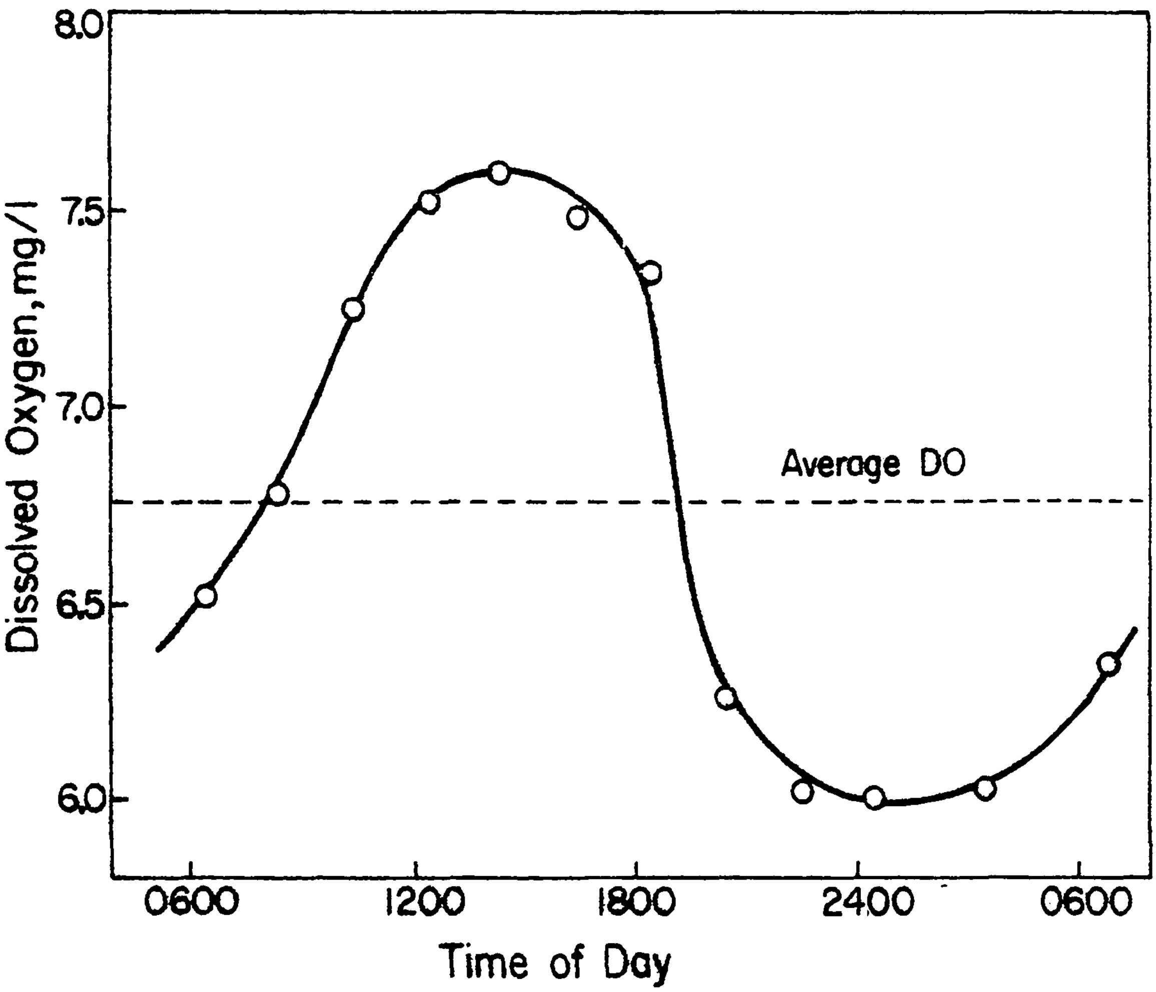

Fig. 58. Diurnal dissolved oxygen relationship with a high base flow (about 100 cfs) in the Skunk River, July 1966.

of the DO profile in the study reach. In cooperation with the staff and operating personnel of the Ames water pollution control plant, the biochemical oxygen demand discharged to the stream was increased from 20 to 25 mg/l BOD_5 to a level of 100 to I25 mg/l.

The purpose of this increase was to determine the magnitude of the assimilative capacity of the stream at the lower levels of stream discharge that were then being experienced, and while the weather was still warm. A concentrated effort was expended during this period by the plant administrative staff, operating personnel and the research group. The results of these special studies are reported in the following sections.

2. Observations during a secondary treatment period in August

The first day and night dissolved oxygen profile study was conducted on August 2 and 3, 1966. The streamflow was about 15 cfs, with an additional 4.6 cfs discharged to the stream as effluent at the outfall. This provided a dilution ratio of about 3.3:1 in the receiving stream. The records of the water pollution control plant indicated a final effluent BOD_5 of 20 to 23 mg/l, with a raw sewage BOD_5 of 100 to 150 mg/l. The pasteurized final effluent samples gave a BOD_5 of 5 to 7 mg/l with all three trickling filters in operation, indicating a high degree of treatment efficiency.

The stream BOD and water quality information are included in Tables 83 and 90. The dissolved oxygen values are listed in Table 93. The results are plotted in Fig. 59 along with the results of the run on August 17 to 19 when only primary treatment was given to the municipal

Table 93. Observed values for dissolved oxygen profile, Skunk River, August 2 and 3, 1966[a]

Time, CDT	Location	Mile point	Description	DO mg/l	Water temperature Deg C	Deg F
Day run						
1300	SK-1	0.0	Gaging station	9.39	25.0	77
1315	SK-2B	0.38	Below outfall	8.91	24.5	76
1345	SK-3	1.80	First bridge	9.30	25.	77
1415	SK-4	2.93	Second bridge	10.73	26.3	79
1445	SK-4A	3.23	I-35 bridge	11.42	26.5	80
1515	SK-5	5.34	Third county bridge	12.66	27.2	81
1530	SK-6	6.49	Fourth county bridge	11.31	28.2	82
1600	SK-7	8.94	Co. "Y", Cambridge	11.53	28.7	83
1615	SK-8	9.82	SE side of Cambridge	9.95	29.0	84
Night run						
2400	SK-1	0.0	Gaging station	5.81	19.	66
0010	SK-2B	0.38	Below outfall	6.01	21.0	70
0045	SK-3	1.80	First bridge	4.97	—	—
0115	SK-4	2.93	Second bridge	4.91	19.0	66
0200	SK-5	3.23	I-35 bridge	4.97	18.5	65
0215	SK-6	5.34	Third county bridge	5.43	18.5	65
0245	SK-7	6.49	Fourth county bridge	5.77	18.5	65
0320	SK-8	8.94	Co. "Y", Cambridge	6.23	18.2	64
0340	SK-9	9.82	SE side of Cambridge	6.46	18.5	65

[a]Complete treatment, all three trickling filters in operation.

wastes. The dissolved oxygen profile for daytime conditions does not exhibit the characteristic spoon-shaped curve of Fig. 3, but it illustrates instead the effect of the algal environment. The initial oxygen sag is discernible, but the stream DO is rapidly replenished by reaeration and the oxygen produced by algae in the photosynthesis cycle. The nighttime DO profile, during the respiration phase of the algae, illustrates the characteristic oxygen sag curve but is

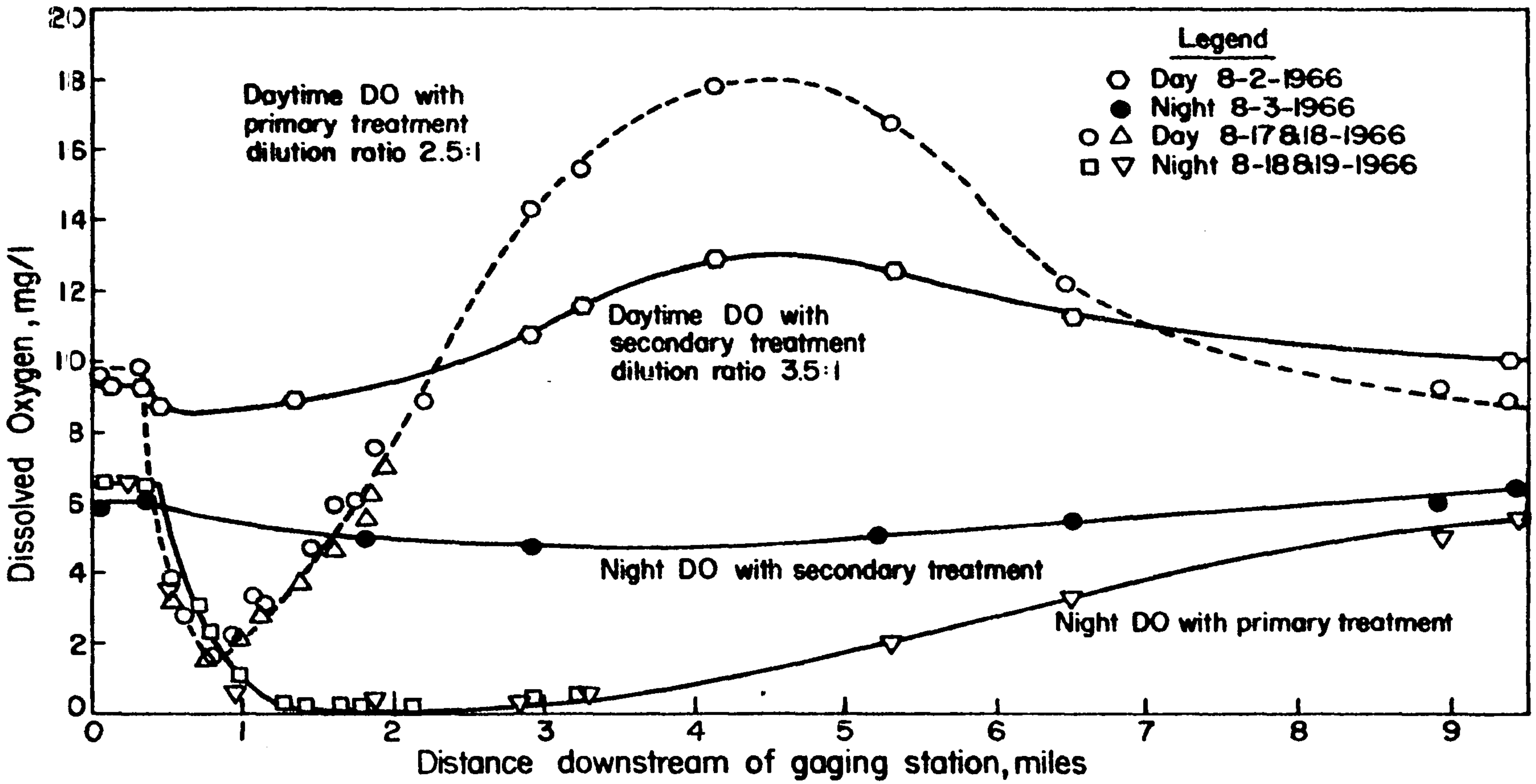

Fig. 59. Typical dissolved oxygen profiles for daytime and nighttime periods, summer season, illustrating DO envelope curves for the reach downstream of Ames, Iowa.

depressed more at the sag point than would occur otherwise.

3. Effect of primary effluent on the stream environment in mid-August

a. Plant control and dissolved oxygen observations   Beginning on August 9, 1966, the trickling filters were flooded and a simulated primary effluent was discharged to the stream. Inadequacies in the valves and piping arrangements at the plant prevent primary effluent from being discharged directly to the stream. The only practical method for increasing the BOD level in the stream was to flood the filters to remove them from effective operation. The additional settling volume offered by the filters produced a final effluent that was high in BOD but low in suspended solids. Following the test period, a considerable amount of solids was flushed from the filters to the final settling tank.

The BOD_5 discharged to the stream during the period August 9 to 20 varied from 90 to 125 mg/l. This additional waste load caused the river water quality to deteriorate rapidly. Streamflow was about 11 cfs and the plant discharged about 4.5 cfs during this period, giving a 2.5:1 dilution ratio. An intensive sampling program was conducted on August 17 to 19 prior to returning the trickling filters to service. Visual inspection was made of the general stream conditions throughout the reach, and sample runs were made to establish DO profiles, BOD levels and levels of the other water quality parameters.

The dissolved oxygen profile data for the August 17 to 19 period are included in Table 94 and in Fig. 59. The daytime results show

Table 94. Observed values for dissolved oxygen profile, Skunk River, August 17-19, 1966[a]

Station code No.	Mile	Location	DO (mg/l) Run I Day[b] 8/17	Run I Night[c] 8/18	Run II Day[d] 8/18	Run II Night[e] 8/19
SK-2	0.190	Bridge on U.S. No. 30			9.5	6.62
SK-2A	0.375	20 ft north of outfall	11.2	6.5	9.86	
SK-2B	0.470	200 ft below outfall			3.58	3.04
SK-2C	0.565		3.0	3.0	2.84	
SK-2D	0.788		1.6	2.7	1.84	
SK-2E	0.975	Windmill station	2.1	0.5	2.38	0.50
SK-2F	1.4				3.44	
SK-2G	1.10		2.8	0.2±	3.10	
SK-2H	1.40		3.7	0.2±	4.96	
SK-2I	1.65		4.5	0.2±	6.06	
SK-2J	1.75	150 yd north of bridge	5.5	0.4		
SK-3	1.80	Unimproved road	5.8			0.36
SK-3A	1.86	150 yd south of bridge	7.0		7.46	
SK-3B	2.05			0.1		
SK-3C	2.30			(Trace)	8.74	
SK-4	2.93	Bridge, county road "T"		0.6	14.3	0.2
SK-4A	3.25	I-35 bridge		0.5	15.4	0.4
SK-5					16.8	1.97
SK-6	6.49				12.0	3.38
SK-7	8.94	Bridge, county road "Y"			9.23	4.97

[a]Stations downstream of gaging station below Squaw Creek; Ames water pollution control plant discharged primary effluent during August 9-20 period.

[b]Time: 2:40 P.M. to 4:30 P.M.

[c]Time: 12:40 A.M. to 3:25 A.M.

[d]Time: 2:00 P.M. to 5:00 P.M.

[e]Time: 1:00 A.M. to 4:00 A.M.

Table 94. Cont.

Station code No.	Mile	Location	DO (mg/l) Run I Day[b] 8/17	Night[c] 8/18	Run II Day[d] 8/18	Night[e] 8/19
SK-8	9.82	Bridge, SE of Cambridge			7.98	5.62
SK-9	10.97	Bridge, Hwy. No. 210			8.05	6.25

an impressive recovery of the dissolved oxygen sag, with the DO level recovering in about 3 to 4 mi from a low of 1.8 mg/l to a high of 16 to 18 mg/l. The peak DO location is about 4 to 5 mi downstream of the Ames outfall. The level of DO supersaturation was computed as 242% of saturation at the peak point. During both studies in August, the waste assimilative reach (in which the dissolved oxygen sag curve is found and downstream of which the stream water quality is again at a high level) was about 10 to 15 mi in length.

The DO results show the added effect of algae respiration at night when algal activity adds to the oxygen requirement for bacterial assimilation of organic wastes. During the night, a 2-mi reach was observed in which the DO level was depressed to zero, and the DO was less than 4 mg/l for a distance of 7 mi. However, the stream had substantially recovered in a 12-mi distance.

b. Observations of other water quality parameters Observed levels for the other water quality parameters, excepting BOD, are included in Table 95. The pH of the effluent is lower than the background pH of the stream, but rises to the 8.0 to 8.5 level at the end of the assimilative reach. Diurnal pH effects were not studied; the values

Table 95. Observed water quality in Skunk River during BOD studies, August 19, 1966

Parameter	Value at indicated station Mile 0.0	Mile 0.38	Mile 0.93	Mile 1.80	Mile 2.93	Mile 5.34	Mile 8.94
pH	8.0	7.1	7.2	7.0	7.3	7.5	8.0
Alkalinity, total, mg/l	231.	255.	–	233.	–	231.	247.
Dissolved oxygen, mg/l[a]	9.5	9.8	2.4	7.5	14.3	16.8	9.2
Temperature, daytime, deg F[a]	82.	78.	81.	82.	82.	83.	84.
Ammonia nitrogen, mg/l	0.0	7.9	–	3.8	1.9	2.1	3.0
Organic nitrogen, mg/l	0.0	4.9	–	3.6	4.6	–	2.3
Nitrate nitrogen, mg/l	0.1	0.6	–	0.3	0.4	0.3	0.5
Total nitrogen, mg/l	0.1	13.4	–	7.7	6.9	–	5.8

[a]Values from August 18, 1966, dissolved oxygen run.

presented are daytime values only. Temperatures are depressed in the daytime by the lower effluent temperatures, but increase rapidly in a 5-mi distance to the normal daily maximum. The opposite effect was found to exist in the night runs, if the air and water temperatures dropped below the effluent temperature.

The effect of removing the trickling filter secondary treatment can be seen in the nitrogen values. Large amounts of ammonia and organic nitrogen were now discharged to the stream. All of the forms of nitrogen were depleted in the downstream direction, apparently being used in the assimilative process or being adsorbed or absorbed at the boundary. Algae could use the ammonia directly, or the effect of bacterial oxidation could be involved; probably both were encountered although the nitrate level was too low to be conclusive in illustrating an increase due to conversion from ammonia. The total nitrogen levels definitely decreased in the downstream direction, and the nitrogen balance found in the laboratory work was not in evidence.

c. Results and discussion of the BOD sampling program The ammonia nitrification problem and its associated oxygen demand posed a serious problem in the development of any mathematical model for forecasting water quality in streams. The BOD sampling program was enlarged in this period to provide additional information. Sufficient river water was obtained at each section to permit temporal determination of BOD for three categories of material. One third of the BOD sample was incubated as a "natural" sample. Another third was filtered (Whatman filter paper) to remove all suspended material including the large planktonic forms of algae, and the supernatant incubated. The remaining third was filtered, pasteurized, and reseeded with 24-hr settled raw sewage seed. This third sample was incubated as a filtered and pasteurized sample. It represents the soluble carbonaceous organic waste material which will be oxidized by bacterial and higher organisms in the first week of the BOD test. This three-way method of analysis was developed to determine if the effect of (1) algae respiration and (2) nitrification of ammonia during the BOD incubation period could be detected and perhaps evaluated.

The results of the August 19 BOD analysis are listed in Table 96. The raw data obtained at each station were plotted and faired curves drawn to best fit the data. The plots for each category and each station are included in Appendix D. Seven-day BOD analysis was then made of the results. Daily BOD values were extracted from the faired curves, and L_a and K_1 determined for each BOD curve using the BODMM computer program. These BOD parameter values are also listed in Table 96. The K_1 rates are about the same as obtained in the routine sampling program, varying from 0.04 above the outfall to a range of 0.11 to 0.19 in the assimilative reach, for the natural samples. Slightly lower values were obtained for the other two categories, filtered and filtered-pasteurized. Both the temporal BOD_5 and the L_a values decrease consistently in the downstream direction, except for the last station where L_a values were higher than at the previous station for some unexplained reason. The computational method for determining K_1 and L_a may be quite sensitive to slight variations of curve fitting. The L_a values for the filtered-pasteurized samples were from 55% to

Table 96. Results of BOD studies of Skunk River, August 19, 1966

Station, mile point	Item	Time, days	Biochemical oxygen demand, mg/l Natural	Filtered	Pasteurized, filtered
0.0	BOD	2.90	1.79	–	–
		3.81	2.30	–	–
		4.86	2.86	–	–
		5.88	3.13	–	–
		6.83	3.51	–	–
	L_a	–	7.12		
	K	–	0.0436		
0.38	BOD	0.94	17.2	14.2	10.3
		2.96	30.4	24.3	20.2
		3.94	35.8	29.8	22.3
		4.95	–	–	26.9
		5.98	–	–	29.4
		6.94	–	–	30.6
	L_a	–	46.1	32.7	33.1
	K	–	0.179	0.217	0.149
0.93	BOD	0.92	12.2	10.2	7.1
		2.96	24.1	19.4	14.6
		3.94	–	–	18.8
		4.96	29.0	25.8	20.9
		6.92	–	–	22.6
	L_a	–	33.8	31.3	25.4
	K	–	0.189	0.150	0.153
1.80	BOD	0.87	5.4	4.9	3.1
		2.95	12.8	10.2	6.7
		3.90	–	–	8.1
		4.94	16.4	14.7	8.8
		5.94	–	–	10.5
		6.90	–	–	10.3
	L_a	–	20.8	19.6	11.4
	K	–	0.143	0.119	0.145
2.93	BOD	0.87	3.5	1.8	–
		2.96	7.7	7.4	4.4
		3.86	–	–	6.2
		4.94	10.6	8.70	7.0
		5.92	–	–	7.3
		6.88	–	–	8.5
	L_a	–	14.6	14.4	12.1
	K	–	0.117	0.0816	0.0755

Table 96. Cont.

Station, mile point	Item	Time, days	Biochemical oxygen demand, mg/l Natural	Filtered	Pasteurized, filtered
5.34	BOD	0.88	2.2	–	1.8
		2.96	7.1	5.6	4.3
		3.86	–	8.7	5.4
		4.94	9.3	10.4	5.8
		5.90	–	–	7.4
		6.86	–	–	8.1
	L_a	–	9.28	8.8	8.9
	K	–	0.183	0.154	0.0570
8.94	BOD	0.83	–	2.1	1.0
		2.95	6.4	5.8	2.9
		3.86	–	–	3.4
		4.94	7.8	7.2	4.2
		6.86	9.4	–	5.4
	L_a	–	13.2	15.4	11.6
	K	–	0.109	0.0698	0.0732

90% of the natural sample L_a values. Results for the filtered samples showed no consistent trend other than the fact that the BOD curves were intermediate to the other two categories. For some of the stations, the L_a values for the filtered samples were almost the same as for the natural samples and for some the L_a values were lower, being not much different from the filtered-pasteurized sample results. Presumably, in a clean stream environment with little or no ammonia, the filtered BOD curve would be closer to the filtered-pasteurized BOD curve since most of the difference would be attributed to the algae respiration. In a polluted reach with few or no algae but with high ammonia values, the filtered BOD curve might approach the natural BOD curve. Combinations of the two, algae and ammonia, would be intermediate. The results show no definite trend, although algae could be discerned in some samples by the greenish tinge, which became more predominant in the fall season. Inspection of the plots in Appendix D does illustrate the magnitude of the difference in the material sampled. The filtered-pasteurized results are a first approximation of the carbonaceous BOD demand, with the natural sample being the combined effect of algae respiration during the BOD test, the nitrogenous BOD and the carbonaceous BOD demands. Excepting for the carbonaceous and nitrogenous BOD demand of suspended material not associated with the algae, the filtered sample results provide an indication of the combined nitrogenous and carbonaceous BOD demand.

d. Analysis of river deoxygenation rates   The time of travel results were used in an analysis of river deoxygenation (K_1) rates for the August 19 run. The time of travel from station to station was computed for the combined discharge levels experienced during the run. The BOD_5 and L_a values were then plotted on a time basis instead of a spatial basis providing an initial indication of the river rate of removal and/or assimilation of organic wastes. The results are shown in Figs. 60 and 61, for all three categories (natural, filtered, and filtered-pasteurized samples).

High river K_1 rates are obtained for the reach immediately downstream of the outfall, with reduced values in the recovery zone of the stream. The initial values for all three categories of material are about the same, 2.1 to 2.3 per day for the BOD_5 results and 1.6 to 2.4 for the L_a results. The L_a data, obtained through computations using the method of moments, are more erratic than the BOD_5 values, as can be seen in comparing the results of the two figures. It would appear that

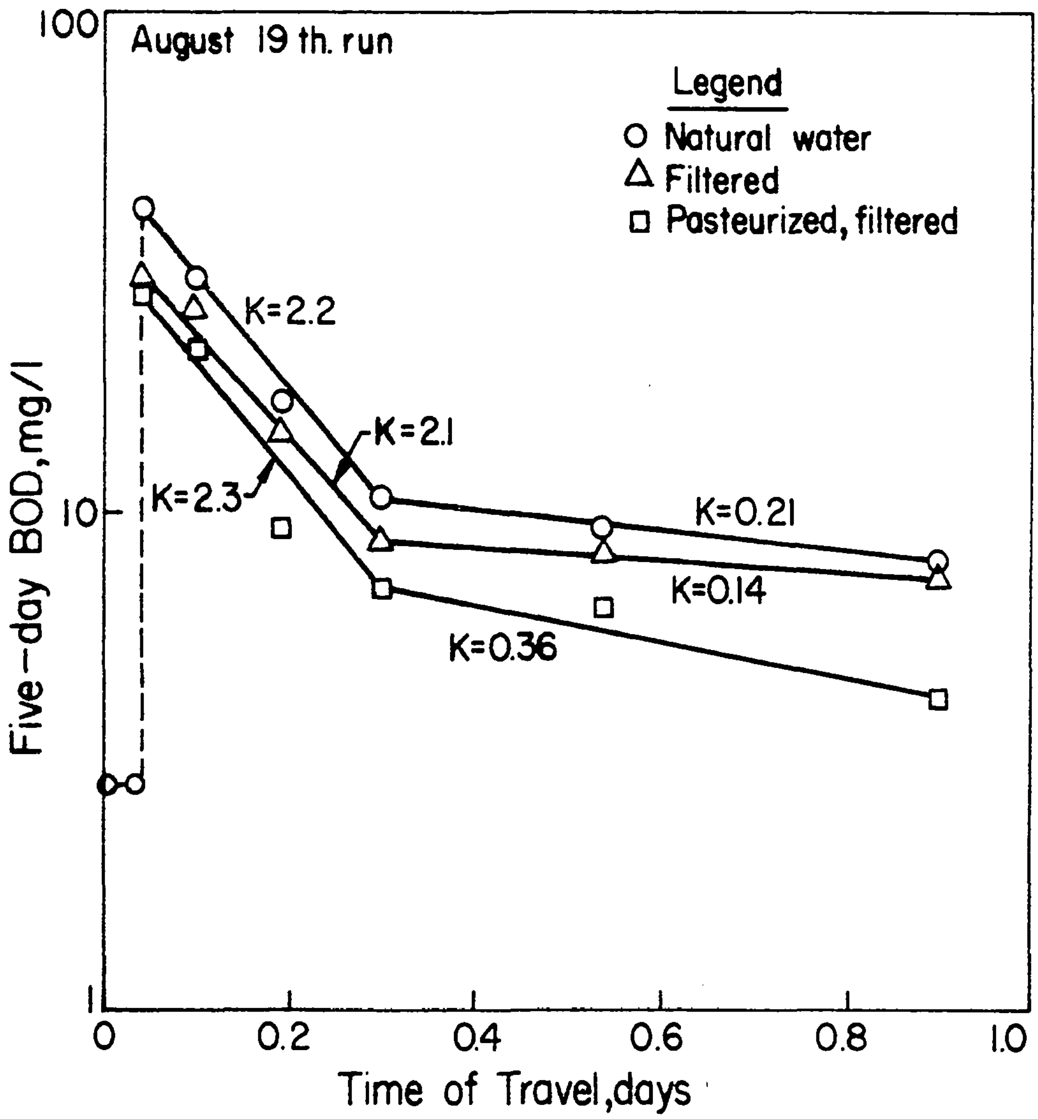

Fig. 60. Reduction of BOD_5 in the downstream direction for the test period of August 17 to 19, 1966.

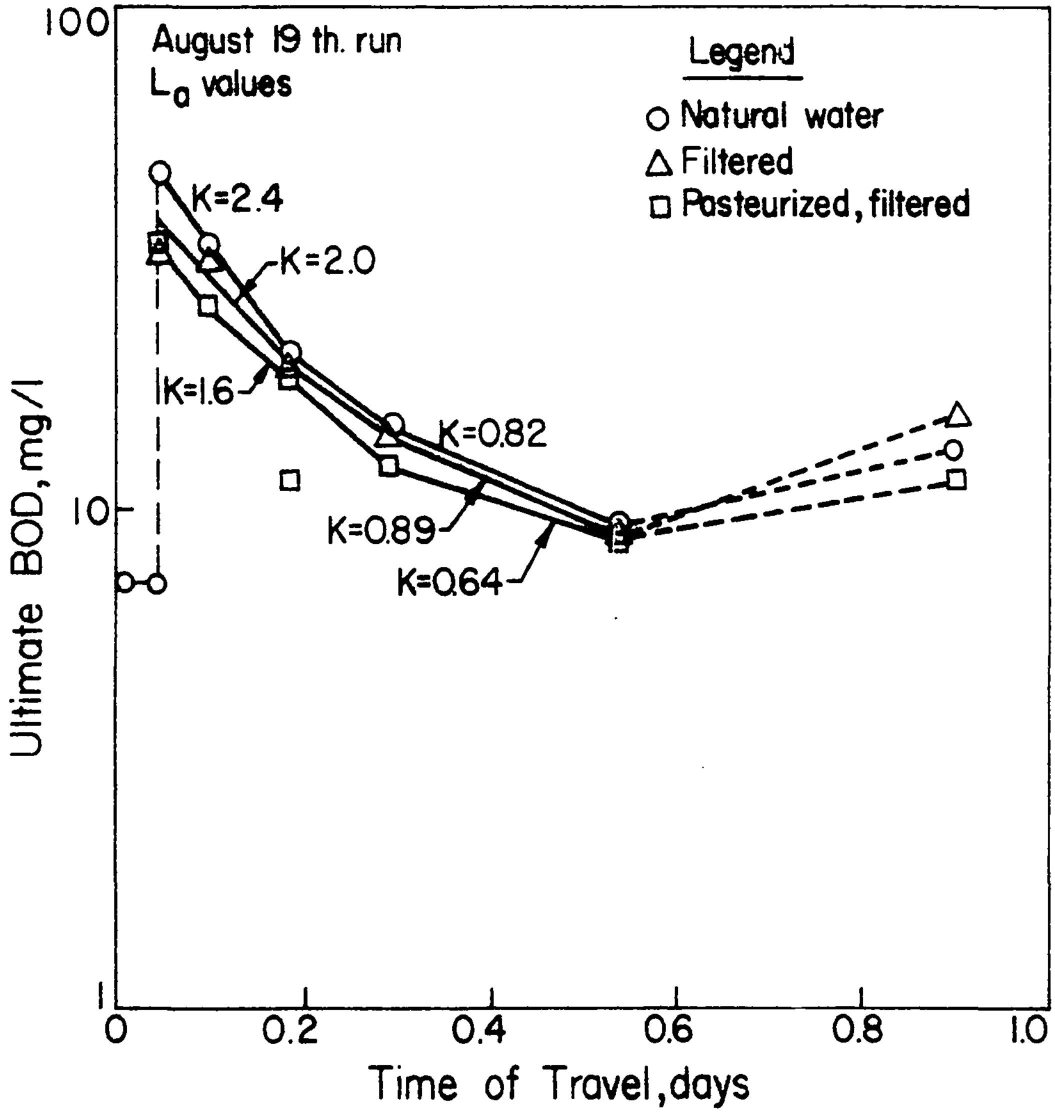

Fig. 61. Reduction of L_a values in the downstream direction for the test period of August 17 to 19, 1966.

for carefully controlled stream surveys and related conditions, the BOD_5 determinations might be more useful than the computed L_a values in evaluating the river K_1 rates.

Because of the added discharge experienced in the downstream direction and of bank load contributions which can be expected at the boundary, the reduction of either BOD_5 or L_a to some base level can be expected, for each category of material sampled. Therefore, the curves in Figs. 60 and 61 are realistic and the K_1 rates observed at the outfall are an initial indication and first approximation of the removal rate for organic wastes discharged to the stream at the outfall. Downstream one might expect the K_1 rates to decrease to very low values as computed and plotted since the bank load contribution is not considered in this analysis. Therefore, the downstream values have less meaning, due to the added BOD contributions which obscure the actual K_1 rates.

4. A second study of secondary treatment levels in late summer

a. General approach   A brief stream rise occurred following the August 17 to 19 sampling period. Although not appreciable, it was sufficient to flush out most of the residue remaining after the primary treatment study phase of August 9 to 20. Measurements were made in late August and early September to evaluate conditions during complete secondary waste treatment, and then various phases of partial secondary treatment were introduced to progressively increase the BOD discharged to the stream. This fall study phase extended through October. One filter (of a total of three in service) was flooded in September and an additional filter was flooded in the October studies.

It was during this fall phase that Shobe (1967) concentrated on the study of the diatom communities. Streamflow receded back to 10 cfs by the end of August and was down to 0.9 to 1.1 cfs in late September and further reduced to 0.1 in late October. During this period, the Ames effluent (4 to 5 cfs) became the major contribution to streamflow in the reach below Ames.

b. Results and discussion of observations The dissolved oxygen profile and temperature data for this run are listed in Table 97. The reach sampled extended from Ames to a point downstream of Cambridge. Warm temperatures were experienced in the daytime, but the air cooled rapidly in the evening. The DO profile data are plotted in Fig. 62, along with the later September data when partial secondary treatment was given to the Ames effluent. The late August results confirmed the results obtained in the August 2 to 3 period of secondary treatment.

Streamflow was at a level of 9 to 10 cfs for the 2-day period. With 4.5 to 4.8 cfs being discharged from the water pollution control plant, the dilution ratio was about 2:1. Slightly higher DO levels were experienced in the daytime in comparison to the August 2 to 3 period, and slightly lower DO values were recorded at night. The nighttime low DO of 3.5 mg/l is below the desired minimum DO level of 4 mg/l required for a warm water aquatic habitat. DO levels were less than 4.0 mg/l from mile 1.0 to mile 6.0. Supersaturation of DO occurred in the daytime, with a maximum of 175% at the peak of the DO profile.

The measured values for other water quality parameters are listed in Table 98. About the same results were obtained as during the early

Table 97. Observed values for dissolved oxygen profile, Skunk River, August 30-31, 1966

Time, CDT Day	Time, CDT Night	Station	Stream mileage from gage miles	Location	Dissolved oxygen mg/l Day	Dissolved oxygen mg/l Night	Water temperatures Deg C Day	Water temperatures Deg C Night	Water temperatures Deg F Day	Water temperatures Deg F Night
1600	0045	SK-2A	0.37	20 ft north of outfall	10.6	5.77	30.		86	
1555	0045	SK-2B	0.38	WPC outfall						
			0.420	North 200 ft below outfall	8.8	5.83	27.4	23.	81	73
1545		SK-2C	0.56		9.2		28.2		82	
1535		SK-2D	0.79		9.48		28.2		82	
1525	0050	SK-2E	0.98	Windmill	9.52	4.61	28.2	23.	82	73
1520		SK-2F	1.04		9.48		28.9		84	
1515		SK-2G	1.10		10.1		29.1		84	
1505		SK-2H	1.40		10.1		29.0		84	
1455		SK-2I	1.65		10.2		28.7		83	
1445	0110	SK-3	1.80	Dead-end road and bridge	10.3	4.13	28.6	21.	83	70
1440		SK-3A	1.86		11.3		28.8		84	
1435		SK-3B	2.05		11.6		28.3		82	
1425		SK-3D	2.40	North side section 25	11.9		28.0		82	
1420		SK-3E	2.45		12.6		28.0		82	
1410		SK-3F	2.75		12.6		27.8		82	
1400	0120	SK-4	2.93	County road "T"	12.6	3.44	27.4	21.	81	70
1407	0130	SK-4A	3.25	I-35	13.1	3.37	27.0		81	
1430	0250	SK-4B	4.30		12.9	3.29		21.5		71
1445	0145	SK-5	5.34	County road	12.6	3.75	29.	21.5	84	71
1450	0200	SK-6	6.49	County road	12.5	4.61		21.5		71
1510	0210	SK-7	8.94	County "Y"	12.6	5.53	30.	21.5	86	71
1530	0220	SK-8	9.82	County road	11.2	6.03	30.5	21.5	87	71
1600	0230	SK-9	10.97	Highway No. 210	10.2	6.10	30.5	22.	87	72

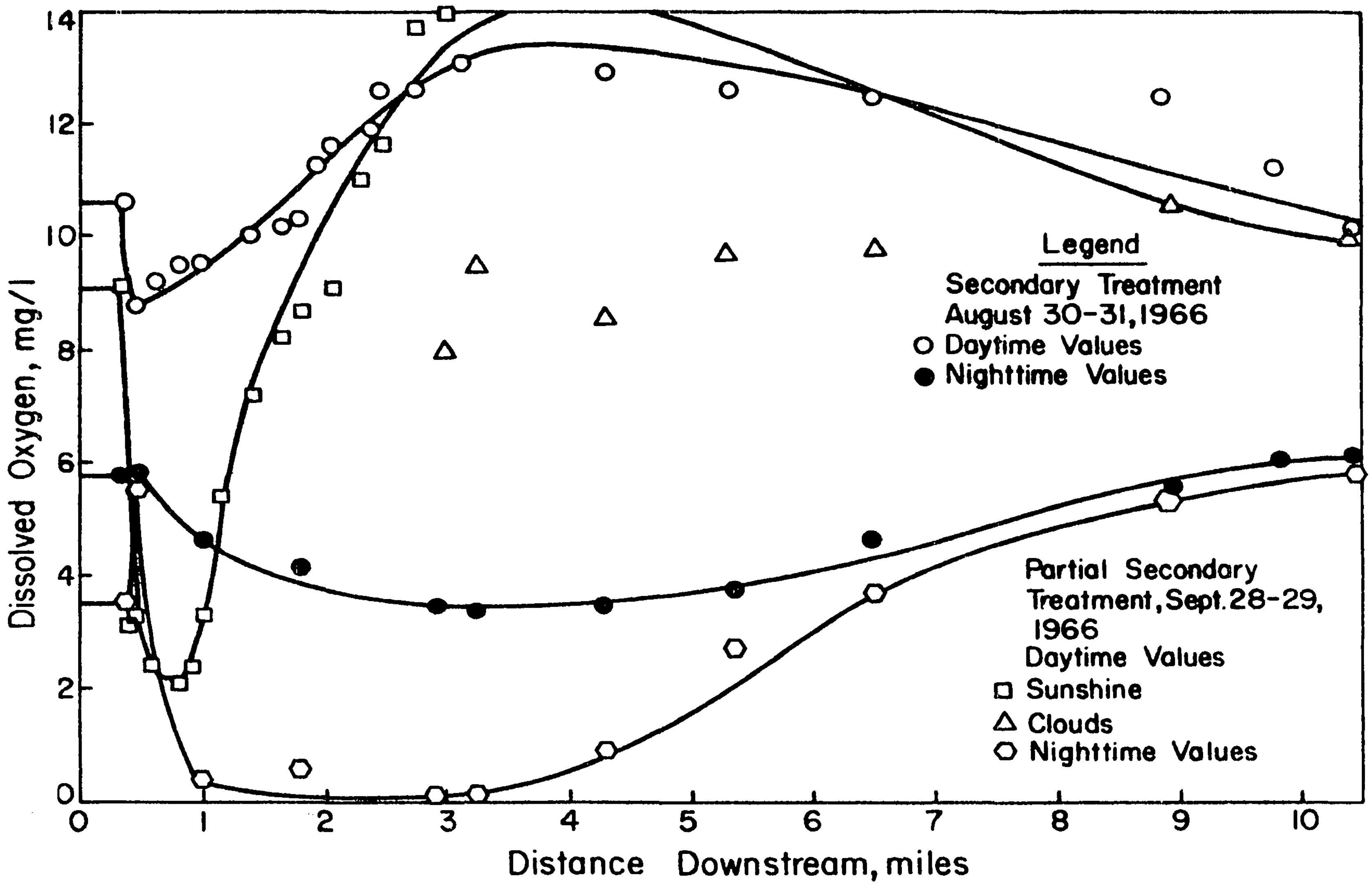

Fig. 62. Dissolved oxygen profiles for both secondary and primary treatment levels, August and September 1966.

Table 98. Observed water quality in the Skunk River during BOD studies, August 31, 1966

Parameter	Value at indicated station Mile 0.0	Mile 0.38	Mile 1.80	Mile 2.93	Mile 5.34	Mile 8.94
pH	8.4	7.9	8.0	–	8.1	8.2
Alkalinity, total, mg/l	233.	219.	227.	–	226.	218.
Hardness, mg/l $CaCo_3$	343.	312.	352.	–	356.	338.
Dissolved oxygen, mg/l[a]	10.6	8.8	10.3	12.6	12.6	11.2
Temperature, deg F[a]	82.	78.	80.	80.	81.	81.
Turbidity, JTU	4.2	5.1	3.5	–	5.9	5.0
Ammonia nitrogen, mg/l	0.5	5.6	1.3	–	1.2	1.1
Organic nitrogen, mg/l	0.4	1.1	1.0	–	0.8	1.0
Nitrate nitrogen, mg/l	0.3	1.7	1.2	–	0.8	0.9
Total nitrogen, mg/l	1.2	8.4	3.5	–	2.8	3.0
Orthophosphate	0.4	11.2	5.6	–	5.3	4.4
Iron, mg/l	0.9	0.6	0.8	–	0.8	0.7
Chlorides, mg/l	23.	30.	–	–	18.	19.
Sulfate, mg/l	118.	182.	155.	–	166.	145.
Silica, mg/l	22.	20.	21.	–	20.	22.

[a]Daytime values.

August run with complete secondary treatment. All forms of nitrogen decreased in the downstream direction, as did the orthophosphate concentration. The plant operation data indicated a BOD_5 of the effluent of 20 to 25 mg/l for the period August 30 to September 1, and a pasteurized final effluent BOD_5 of 14 to 18 mg/l. The raw sewage BOD_5 had increased to a level of 150 to 170 mg/l.

The same BOD program was followed for this study as for the August 17 to 19 run, permitting the complete secondary treatment phase to be evaluated. The temporal BOD data are included in Table 99. As before, the data were plotted, faired curves drawn, and daily BOD values extracted for BOD parameter determination. The plots are included in

Table 99. Results of BOD studies of the Skunk River, August 31, 1966

Station, mile point	Time, days	Item	Biochemical oxygen demand, mg/l Natural	Filtered	Pasteurized, filtered
0.0	0.93	BOD	1.41	–	–
			3.61	–	–
			4.60	–	–
			5.85	–	–
		L_a	7.49	–	–
		K	0.0937		
0.38	1.02	BOD	3.68	1.90	1.40
	3.02		8.46	5.22	4.43
	4.98		12.44	7.30	5.06
	7.03		–	8.78	6.20
		L_a	21.48	12.36	7.45
		K	0.0758	0.0787	0.133
1.80	1.02	BOD	1.52	0.88	0.53
	3.02		3.78	2.15	2.29
	4.98		5.21	3.17	2.46
	7.04		6.81	–	2.55
		L_a	10.04	5.43	3.66
		K	0.0677	0.0796	0.104
2.93	1.0	BOD	0.94	–	0.46
	3.0		3.19	–	1.39
	4.96		5.92	–	1.97
	6.98		–	–	2.50
		L_a	11.22		3.80
		K	0.0486		0.0754
5.34	0.97	BOD	1.88	1.14	0.99
	2.97		4.12	2.89	2.27
	4.94		4.91	4.11	2.83
	6.98		5.50	5.16	3.43
		L_a	6.10	6.13	3.98
		K	0.159	0.0983	0.124
8.94	0.98	BOD	1.83	1.21	1.59
	2.98		2.90	3.26	1.97
	4.95		4.17	4.30	2.49
	6.98		5.35	4.97	3.14
		L_a	5.68	5.27	3.34
		K	0.144	0.151	0.141

Appendix D. The values of L_a and K_1 as obtained through computer analysis are included in Table 99.

The laboratory values of K_1 listed in Table 99 are lower for this secondary treatment phase, in comparison to the primary treatment results. This is in agreement with the laboratory results obtained during the studies of final effluents and mathematical analysis of BOD data of both raw sewage and effluents from the several types of treatment processes. Values of K_1 for the August 30 to 31 study varied from 0.05 to 0.16, with most values being in the 0.08 to 0.14 range.

The values of L_a remained on the low side for the complete secondary treatment study. Values ranged from 5.7 to 21 mg/l for the natural samples and 3.3 to 7.5 mg/l for the filtered-pasteurized samples. The results of the filtered sample analyses were intermediate once again.

c. Analysis of river deoxygenation rates for the August 30 to 31 period The temporal variation of L_a and BOD_5 for this run was also studied. The plotted data are shown in Figs. 63 and 64. The K_1 values were about the same as observed in the mid-August period with primary treatment. The values of K_1 vary from 2.3 to 2.5 for the BOD_5 results, and from 2.1 to 2.4 for the L_a results. No appreciable change in BOD_5 or L_a values was observed after the first few stations. It should be noted that the K_1 values indicated in Figs. 60, 61, 63 and 64 represent values at the temperature of the stream, and have not been reduced to the common 20 deg C base. The laboratory results discussed previously were all obtained at the 20 deg C level. An equivalent

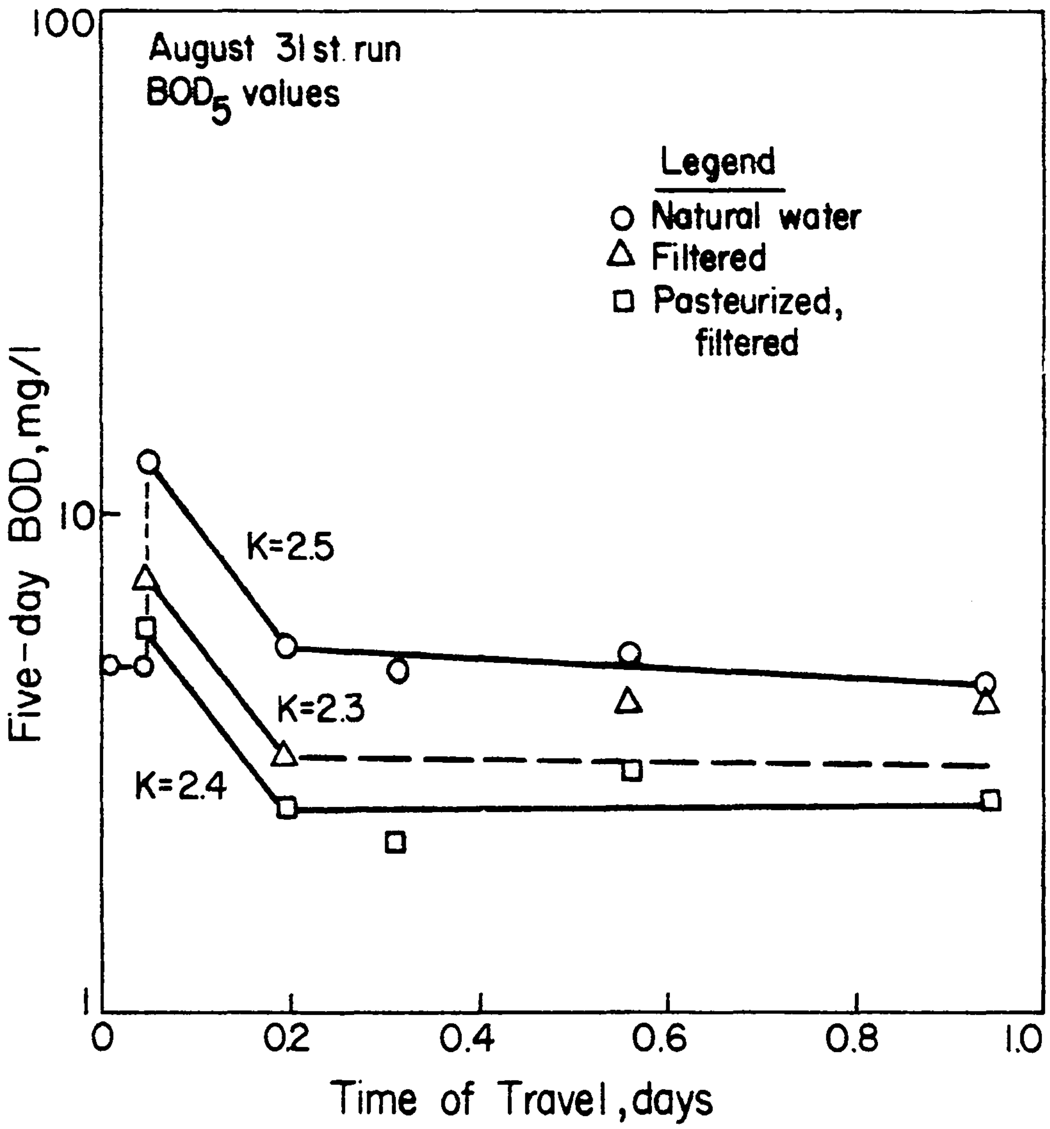

Fig. 63. Reduction of BOD_5 in the downstream direction for the test period of August 30 to 31, 1966.

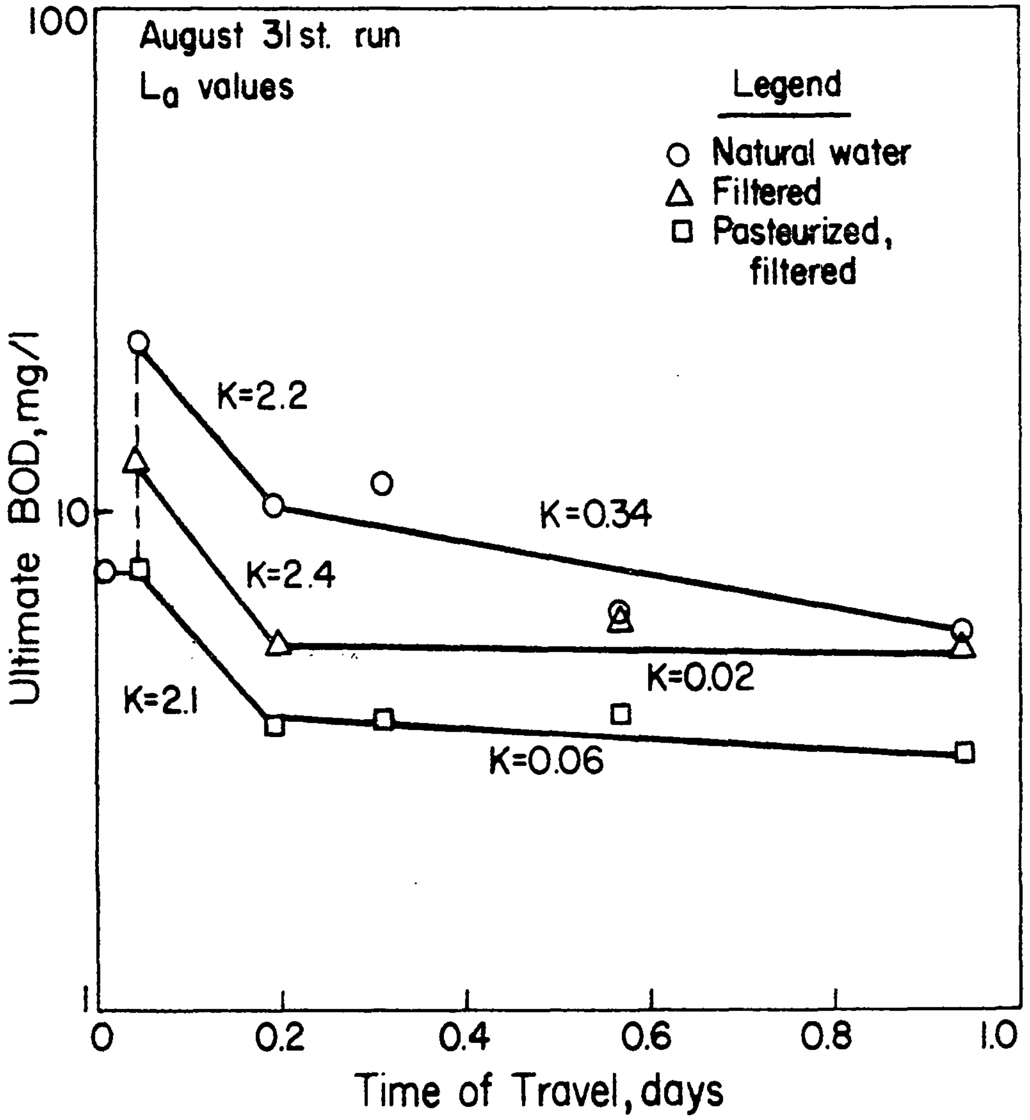

Fig. 64. Reduction of L_a in the downstream direction for the test period of August 30 to 31, 1966.

adjustment for the river K_1 values was made at the conclusion of all the analyses, summer, fall and winter, and will be discussed later.

d. Diurnal temperature and dissolved oxygen variations The stream discharge decreased to a low level of 5.7 cfs on September 7, at which time it varied little from the effluent discharge of 4.7 cfs. A diurnal dissolved oxygen study was conducted during the 24-hr period commencing on noon, September 7. The purpose of this study was to determine the average DO levels in the assimilative reach and to provide additional information concerning the influence of the algal environment during the fall season. Temperature and DO data are listed in Table 100 for this diurnal study.

Temperatures were not as high as occurred during the summer study periods, and the effluent discharge began to exert a stabilizing influence on the stream temperature, as indicated in Table 100. Dissolved oxygen levels reached a maximum of 10 mg/l at mile 3.0, with a supersaturation value of 126%. Values at downstream stations probably would have been higher, but were not sampled. With the minimum nighttime DO levels being experienced between mile points 3 and 4, the data in Table 100 provide an indication of the minimum DO for the reach, but not the maximum daytime value.

A minimum nighttime DO value of 2.8 mg/l was measured at mile 3.0, with complete secondary treatment in operation. The dilution ratio was 1.2:1. Plant operation records indicated a raw sewage BOD_5 of 170 mg/l, a final effluent BOD_5 of 52 mg/l, and a pasteurized final effluent BOD_5 value of 36 mg/l. This indicates a lower plant efficiency than obtained in the previous month at higher air and water temperatures, and

Table 100. Observed values of diurnal variation in dissolved oxygen for the fall season[a]

Mile 0.0					Mile 0.40					Mile 3.0				
Time, CDT	Water temp. Deg C	Water temp. Deg F	DO mg/l	Percent saturation	Time, CDT	Water temp. Deg C	Water temp. Deg F	DO mg/l	Percent saturation	Time, CDT	Water temp. Deg C	Water temp. Deg F	DO mg/l	Percent saturation
1230	22.2	72	9.60	115	1235	22.2	72	6.90	82	1250	21.8	71	9.10	108
1425	25.4	77	9.38	119	1430	24.0	75	4.25	53	1445	25.0	77	9.97	126
1625	25.3	77	9.42	119	1835	24.6	76	7.43	93	1650	25.7	78	9.89	126
1835	23.3	73	9.02	110	1840	22.9	73	6.31	77	1855	23.2	73	4.08	50
2035	22.1	72	6.92	83	2045	22.0	72	5.71	68	2100	20.5	69	3.72	43
2235	18.0	64	6.67	73	2245	19.5	67	5.22	59	2305	18.4	65	2.82	31
0035	17.0	63	7.15	77	0045	19.5	67	5.32	60	0100	16.5	62	3.15	33
0235	15.5	60	7.36	77	0245	19.0	66	5.93	66	0305	15.0	59	3.28	34
0430	14.7	58	7.60	78	0435	16.8	62	6.61	71	0455	14.5	58	3.20	33
0630	13.7	56	7.69	77	0635	15.0	59	7.10	73	0650	13.4	56	3.57	36
0830	13.3	55	8.50	84	0835	15.5	60	7.40	77	0850	14.0	57	4.69	47
1030	16.0	61	9.31	97	1035	19.0	66	7.76	87	1050	16.5	62	7.00	74
1230	21.0	70	9.72	113	1235	21.5	71	7.12	84	1250	21.0	70	9.08	106
Average daily DO value			8.3					6.4					5.7	

[a]Data for September 7-8, 1966; saturation DO values at sea level corrected by 97% for elevation difference; stream discharge, 5.7 cfs; effluent discharge, 4.7 cfs; complete treatment of municipal wastes.

accounts for the increased BOD loading to the river and the resultant lower level of DO in the stream.

The dissolved oxygen data are plotted as an isopleth diagram in Fig. 65. Isopleths of DO are drawn with the time of day as the ordinate and distance downstream as the abscissa. Therefore, a horizontal line represents a dissolved oxygen profile at the selected time of day. The DO profiles of Figs. 59 and 62 were such horizontal profile lines, taken at the peak daytime and at the minimum nighttime DO values, insofar as was possible. The DO isopleths provide a more complete picture of the spatial and temporal diurnal DO variations experienced at and immediately downstream of the Ames WPCP outlet. A vertical line at any spatial location provides the diurnal trace at that point, as was shown previously in Fig. 58.

A velocity slope is included in Fig. 65 to illustrate the estimated stream velocity for the discharge downstream of the outlet. An observer moving at the average stream velocity would progress along the indicated slope as the diagram (or stream) is traversed. Thus, effluent discharged at the outfall at noon on the first day would reach the minimum DO isopleth at about midnight. Effluent from the plant discharged at 0200 would arrive at mile 3.0 during the peak photosynthesis period at that point. If the stream and all other conditions remained stabilized, temporally, then presumably the isopleths would remain the same day after day, and in the same relative position temporally and spatially. This is obviously not true, so a strip chart of isopleths in the vertical direction would be needed to represent, say, a year's record of dissolved oxygen for the stream. A few seasonal

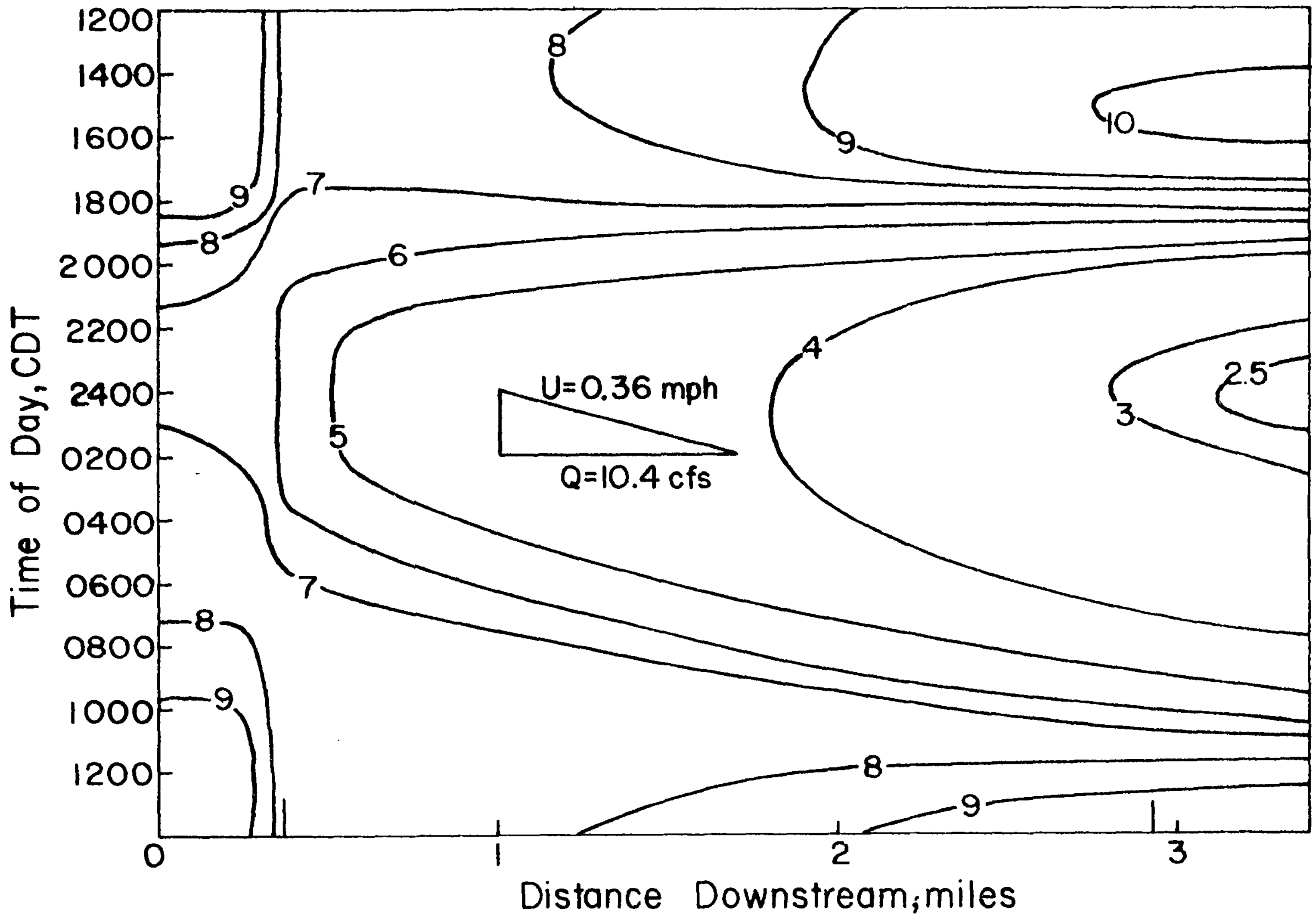

Fig. 65. An isopleth diagram for dissolved oxygen in the Skunk River, September 7, 1966.

isopleths would be useful in recording and analyzing the dissolved oxygen characteristics at critical stream points, especially if they represented critical dilution ratios or maximum BOD loadings for meeting selected dissolved oxygen levels.

5. The fall series of water quality studies

a. Water quality levels for the three periods   The three studies conducted in coordination with the diatom studies of Shobe (1967) provided additional information as the secondary treatment levels were progressively reduced during a low-flow period. The plant operation periods were September 11 to 29, September 30 to October 12, and October 13 to 27. Water quality determinations made during the September to October study period are listed in Table 101. These studies showed little variation in the assimilation of substances discharged as effluent from those experienced previously. Streamflow was 2.2 cfs on September 17 to 19, reduced to 0.1 cfs on October 12, and had increased slightly to 0.8 cfs by October 26, 1966.

Values of pH at the outfall are slightly lower than the stream pH above the outfall; however, the pH values return to the background level in the length of the assimilative reach. Alkalinity and hardness values change very little. The stabilizing effect of the effluent temperature is evident from the temperature data, with the river temperature reaching levels lower than the effluent. The specific conductance values show the increased level of dissolved solids discharged to the stream as the secondary treatment levels were reduced. Turbidity levels increased generally during the three

Table 101. Observed water quality in the Skunk River during fall season river studies

Parameter	Value at indicated station for observation date								
	September 17, 1966			October 12, 1966			October 26, 1966		
	Mile 0.36	Mile 0.38	Mile 3.05	Mile 0.36	Mile 0.38	Mile 3.05	Mile 0.36	Mile 0.38	Mile 3.05
pH	7.7	7.2	7.6	7.6	7.3	7.5	7.4	7.0	7.2
Alkalinity, total, mg/l	225.	213.	233.	210.	202.	220.	220.	190.	211.
Hardness, mg/l $CaCo_3$	230.	280.	292.	240.	295.	290.	260.	320.	315.
Temperature, daytime, deg C	15.4	19.8	17.0	17.7	20.4	18.2	16.8	21.2	17.4
Temperature, daytime, deg F	60.	68.	63.	64.	69.	64.	62.	70.	63.
Ammonia nitrogen, mg/l	1.5	10.5	3.5	1.7	18.6	4.6	1.4	30.5	20.4
Organic nitrogen, mg/l	0.3	1.8	0.4	0.4	1.3	0.0	1.6	6.0	7.0
Nitrite-nitrate nitrogen, mg/l	1.8	2.8	1.1	3.0	4.6	2.8	1.2	2.8	1.4
Total nitrogen, mg/l	3.6	15.1	5.0	5.1	24.5	7.4	4.2	39.3	28.8
BOD_5, mg/l	5.5	13.9	6.2	3.5	55.0	8.6	4.6	114.	42.6
COD, mg/l	0.0	32.0	8.0	0.0	68.0	16.0	16.7	273.	94.1
Iron, mg/l	0.3	0.4	0.4	0.1	0.1	0.1	0.2	0.4	0.4
Orthophosphate, mg/l	1.1	8.4	9.4	1.8	8.2	9.3	1.6	9.4	11.1
Total phosphate, mg/l	1.6	12.4	12.2	2.3	18.4	14.6	2.1	19.3	18.3
Sulfate, mg/l	160.	180.	175.	148.	203.	187.	155.	223.	209.
Silica, mg/l	25.	32.	26.	22.	—	—	20.	—	—
Turbidity, JTU	30.	12.	5.	8.	22.	13.	17.	96.	64.
Specific conductance, micromhos/cm	588.	710.	630.	590.	890.	835.	626.	960.	868.
Discharge, cfs									
Skunk River	2.2			0.2			0.8		
Ames WPCP	4.5			5.2			4.8		

studies. Sulfates, silica and iron did not change appreciably, spatially, or temporally. The concentrations of the other water quality parameters exhibited nonconservative traits, decreasing in magnitude in the downstream direction. These included the several forms of nitrogen, BOD, and COD. For the first time, the phosphate levels did not decrease in the downstream direction, or decreased very little. This may have been due to the low DO levels experienced in the combined study, which remained at zero during much of the day and night in the 3 mi reach. The lower temperatures may also have influenced the assimilative capacity of the stream.

b. Partial secondary treatment, September 11 to 29 For the special study period of September 11 to 29, another DO profile run was made on September 28 to 29. The results are tabulated in Table 102. The DO profile is included in Fig. 62 with the results of the August 30 to 31 complete treatment study. This study in late September confirmed the results obtained in the August 17 to 19 study, as comparison of Figs. 59 and 62 indicates. The DO is depleted in the nighttime in the assimilative reach for a distance of about 4 mi. The daytime oxygen sag curve is brief, with rapid movement to the supersaturation phase. The maximum magnitude of the supersaturation was 160% in the assimilative reach of the stream, occurring at mile 4.0. This study period followed a period of about 3 weeks during which one filter was flooded continuously. The plant records show a final effluent BOD_5 of 50 to 70 mg/l for this period, with 25 to 50 mg/l for the pasteurized samples. Raw sewage BOD_5 varied from

Table 102. Observed values for dissolved oxygen profile, Skunk River, September 28 and 29, 1966[a]

Time Day 9/29	Time Night 9/28-29	Station	Stream mileage	Location	Dissolved oxygen mg/l Day	Dissolved oxygen mg/l Night	Water temperature Deg C Day	Water temperature Deg C Night	Water temperature Deg F Day	Water temperature Deg F Night
1520	2330	SK-2A	0.37	Above outfall	9.1	3.5	14.8	13.8	59	57
1520	2330	SK-2A	0.38	Just below outfall	3.1	5.6	18.8	18.8	66	66
1515		SK-2B	0.42	200 ft below outfall	3.2		18.8		66	
1505		SK-2C	0.56		2.4		18.8		66	
1455		SK-2D	0.79	Line fence	2.1		19.0		66	
1450		SK-2D-1	0.87	Trees	2.4		19.4		67	
1445	2350	SK-2E	0.98	Windmill	3.3	0.2	19.3	17.3	67	63
1435		SK-2G	1.10		5.4		19.0		66	
1425		SK-2H	1.40	(Clouds, storm front moving into area)	7.2		19.0		66	
1415		SK-2I	1.65		8.2		18.8		66	
1400	0015	SK-3	1.80	Dead-end road and bridge	8.7	0.3	18.0	15.0	64	59
1350		SK-3B	2.05		9.1		17.0		63	
1340		SK-3C	2.30		11.0		16.5		62	
1330		SK-3E	2.45	13.5 deg C air temp. 1330 hr	11.7		15.7		60	
1320		SK-3F	2.75		13.7		15.7		60	
1310		SK-4	3.00	300 ft downstream from SK-4 Cold, cloudy	14.4		15.0		59	

[a]Partial secondary treatment, one filter flooded, 3.4 mgd flow from plant.

Table 102. Cont.

Time Day 9/29	Time Night 9/28-29	Station	Stream mileage	Location	Dissolved oxygen mg/l Day	Dissolved oxygen mg/l Night	Water temperature Deg C Day	Water temperature Deg C Night	Water temperature Deg F Day	Water temperature Deg F Night
1620	0030	SK-4	2.93	County road	8.0	0.0	15.5	15.1	60	59
1630	0200	SK-4A	3.25	I-35	9.5	0.1	15.2	15.0	59	59
1645	0050	SK-4B	4.30		8.6	0.9	15.0	15.2	59	59
1655	0110	SK-5	5.34	County road	9.7	2.7	14.8	15.3	59	60
1705	0120	SK-6	6.49	County road	9.7	3.7	14.8	15.1	59	59
1715	0130	SK-7	8.94	County "Y"	10.6	5.4	14.8	15.1	59	59
1720	0140	SK-9	10.97	Iowa No. 210	9.9	5.7	14.8	15.0	59	59
1745		SK-2	0.19		8.5		14.5		58	

180 to 210 mg/l, indicating a stronger domestic and municipal waste under dry weather conditions.

c. Reduced treatment levels for the October studies Two extensive temperature and dissolved oxygen diurnal studies were made in the two October studies. The temperature and DO values are tabulated in Appendix D for this phase. The results were plotted in four figures, two isopleth diagrams for the DO parameter and two isothermal diagrams for the temperatures (Figs. 66, 67, 68 and 69). The slope representing the average stream velocity for each run is also shown. Again, as with Fig. 65, the isopleth and isothermal diagrams provide a detailed picture of the DO and temperature patterns in the stream.

The results shown in Figs. 66 and 68 for dissolved oxygen are for severe loading conditions in the stream. The plant records show that the final effluent BOD_5 was 90 to 95 mg/l in early October, with a level of 80 to 85 mg/l for the pasteurized samples. Raw sewage BOD_5 had increased to 215 to 225 mg/l. For the final phase of the fall studies, additional filters were flooded. The final effluent increased in strength to a level of 125 to 150 mg/l BOD_5, with raw sewage BOD's of 250 to 300 mg/l. As indicated in Table 102, the BOD_5 of the plant effluent increased to 114 mg/l at the time of this last run.

Because of the high BOD_5 of the effluent, and with little or no dilution water at the low levels of streamflow, the dissolved oxygen level of the stream was entirely depleted at the outfall, both in the nighttime and in the daytime. However, for the daytime period during each run the dissolved oxygen makes a rapid recovery through algal

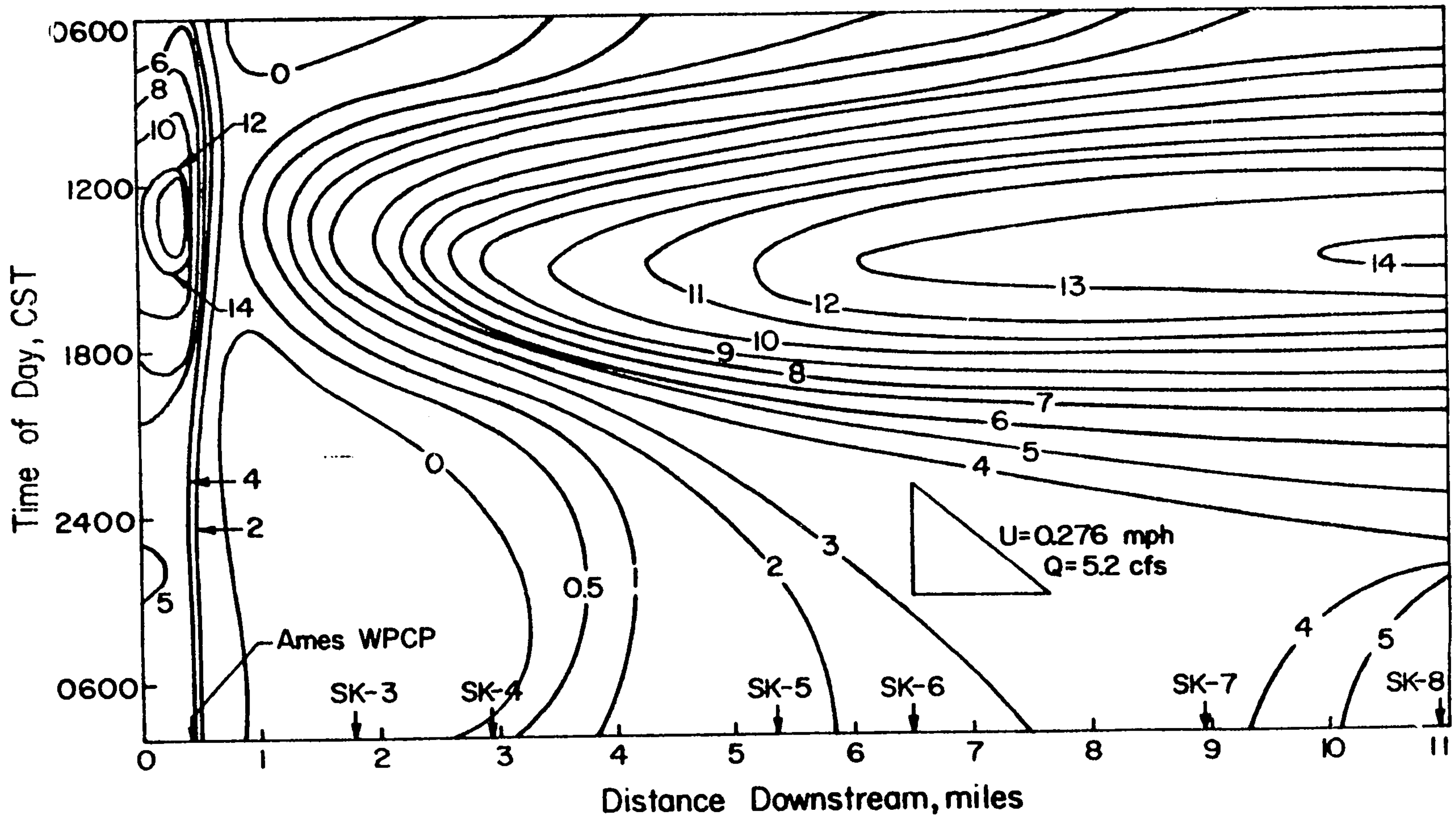

Fig. 66. Dissolved oxygen isopleths for the October 6 and 7, 1966 study period.

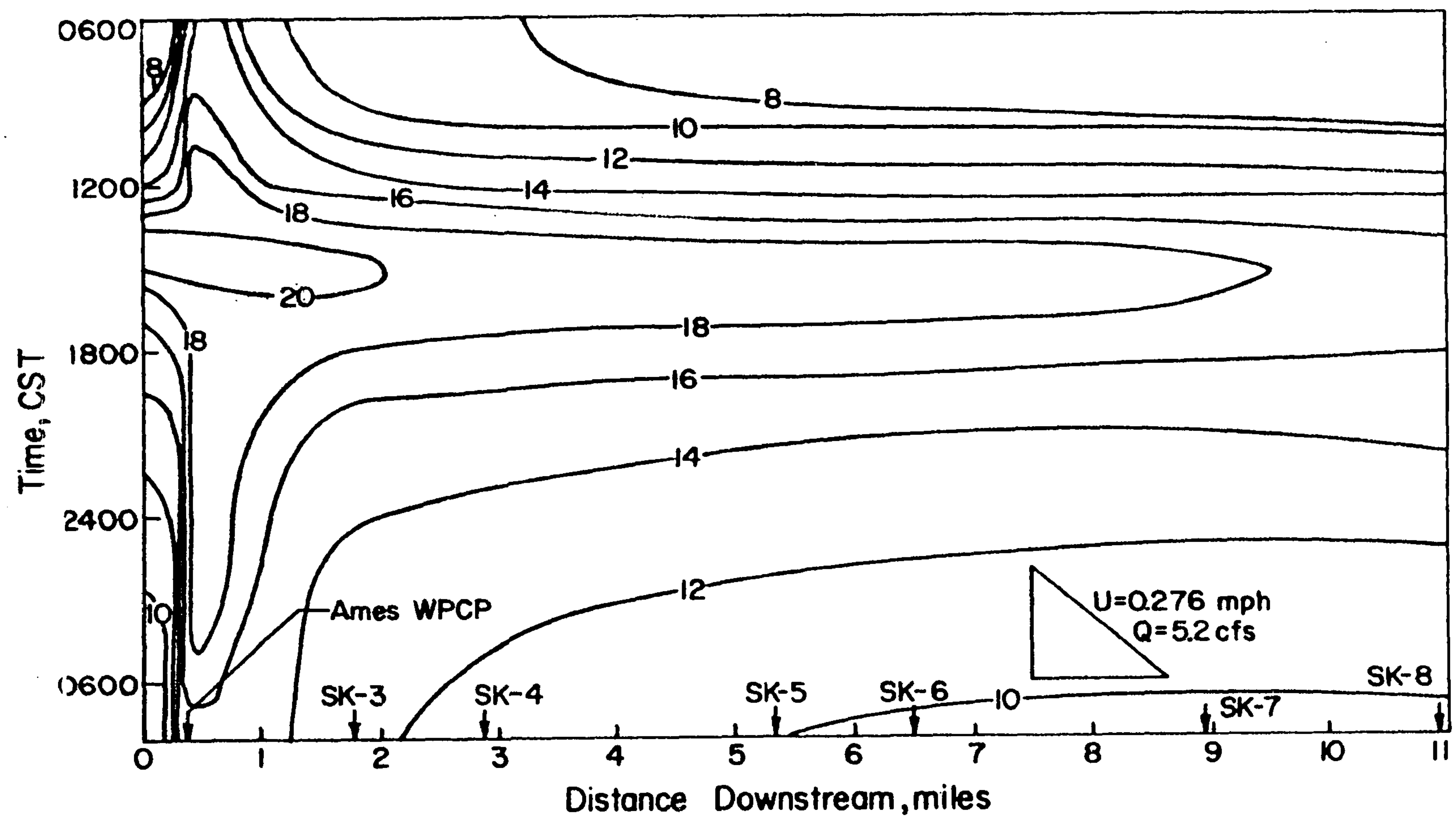

Fig. 67. Isothermal diagram for the October 6 to 7, 1966 study period.

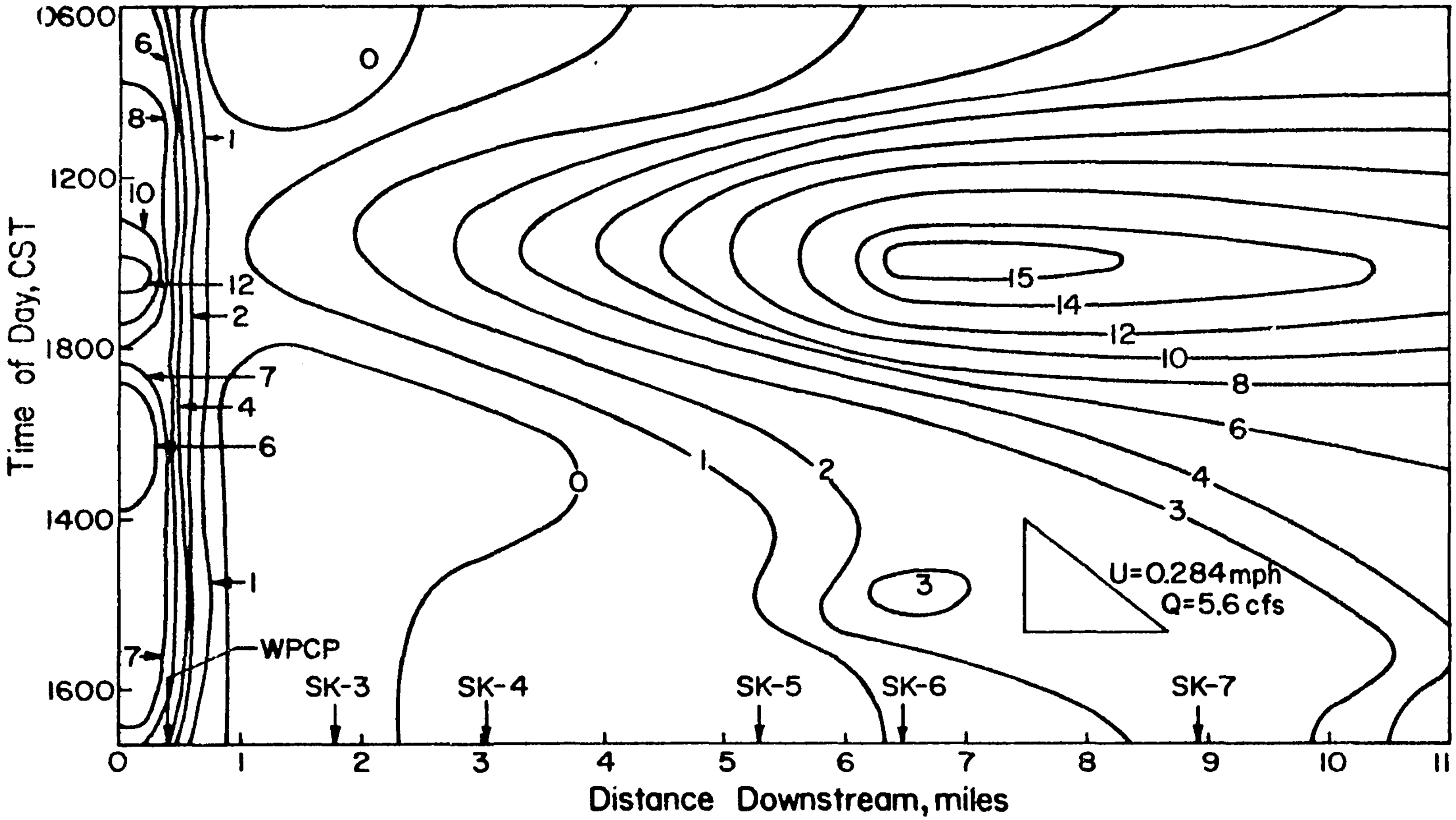

Fig. 68. Dissolved oxygen isopleths for the October 24 to 25, 1966 study period.

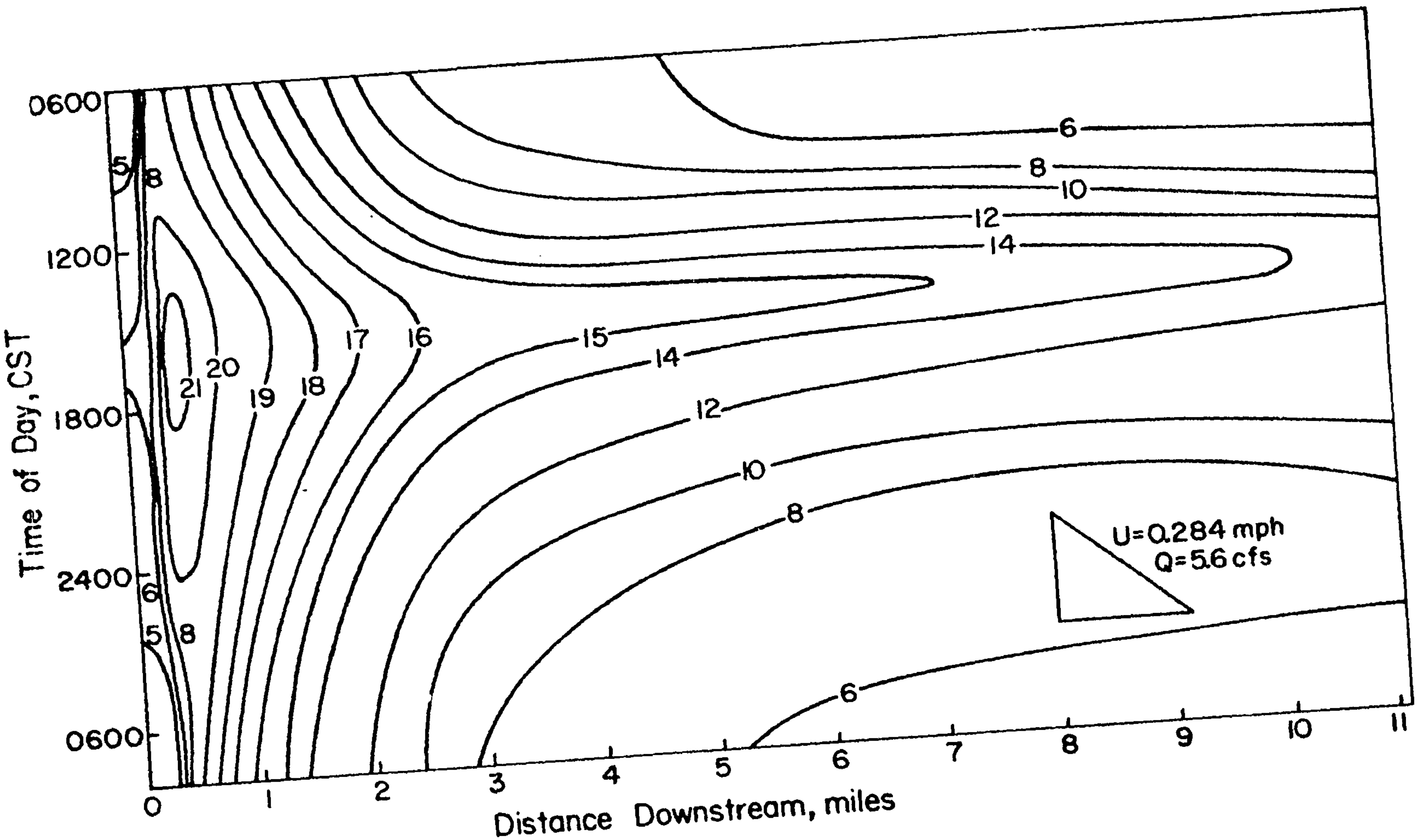

Fig. 69. Isothermal diagram for the October 24 to 25, 1966 study period.

photosynthesis. The values of daytime supersaturation reached 170 to 180% for these two periods of study. Although an asset in the daytime, the algae become a liability in the night phase as respiration exacts its requirements. For the October 24 to 25 study, the nighttime DO level is less than 4 mg/l for the entire 11 mi reach between Ames and Cambridge.

6. Water quality levels in the winter season

Two brief sampling studies were conducted during a winter period, both in January of 1967. The effluent discharged from the Ames water pollution control plant was the only contribution to streamflow during this period. The results of the two studies are listed in Tables 103 and 104. The DO profiles for daytime conditions are shown in Fig. 70. Although the BOD_5 and ammonia levels were high, the dissolved oxygen in the stream was not depleted entirely. However, DO levels of 1 to 2 mg/l were recorded. The total nitrogen levels showed more stability in the downstream direction than experienced in the summer period, and exhibit low levels of conversion of ammonia to nitrates.

Computed laboratory values of K_1 varied from 0.13 to 0.23 in the first run and from 0.06 to 0.16 in the second run. Both BOD_5 and L_a values decrease in the downstream direction. The high levels of BOD_5 at the outfall station indicate relatively low treatment plant efficiency, even with all trickling filter units in operation. Raw sewage BOD_5 at the plant varied from 230 to 250 mg/l, with the final effluent in the range 80 to 100 mg/l. This indicates a plant efficiency of 60 to 65% in the winter season. This confirms the fact that the Ames water pollution control plant is reaching an overload level as

Table 103. Observed water quality levels in the Skunk River during the winter season, Run No. 1-W[a]

Mile point	Temperature deg F	Dissolved oxygen mg/l	BOD mg/l 1-day	BOD mg/l 5-day	BOD mg/l 7-day	Computed BOD parameters L_a, mg/l	Computed BOD parameters K, per day	Phosphates PO_4 mg/l	Ammonia nitrogen mg/l	Nitrate nitrogen mg/l	Suspended solids mg/l
0.0	32	12.5	6.4	14.5	19.0	15.5	0.215	0.5	3.8	10.0	92
0.37	51	9.2	18.3	53.4	–	67.9	0.126	29.3	20.3	9.2	21
1.80	35	6.6	14.3	30.4	46.0	32.0	0.231	19.5	14.8	9.2	–
2.93	33	4.4	13.6	29.5	41.0	30.4	0.234	17.3	18.25	7.5	10
10.97	32	1.6	7.6	22.2	36.0	28.2	0.128	15.2	14.50	7.8	18
17.57	32	2.8	0.8	4.4	6.2	5.3	0.197	12.4	10.20	6.5	–

[a]Data for January 19, 1967, daytime sampling run; effluent discharge, 5.0 cfs; river discharge, 0.02 cfs.

Table 104. Observed water quality levels in the Skunk River during the winter season, Run No. 2-W[a]

Mile point	Temperature deg F	Dissolved oxygen mg/l	Biochemical oxygen demand, mg/l 1-day	5-day	7-day	BOD parameters L_a, mg/l	K, per day
0.00	32	11.0	–	–	–	–	–
0.37	53	5.5	27.9	81.6	117.	105.	0.124
2.93	33	7.5	6.0	20.8	29.4	24.3	0.157
6.49	32	5.8	7.5	19.6	21.4	22.9	0.145
10.97	32	2.4	1.7	6.8	12.2	11.7	0.060
17.6	32	4.7	1.0	4.8	9.3	5.6	0.152

[a]Data for January 23, 1967, daytime sampling run; effluent discharge, 5.1 cfs; river discharge, 0.5 cfs.

was discussed in the chapter relating to population projections, water demand and waste water volumes.

The computed L_a values and BOD_5 values from the faired curves were used to evaluate river K_1 rates for the winter season. The data are plotted in Figs. 70 and 71, as related to the time of travel for the two sampling periods. Again, these rates are uncorrected for temperature variations. High removal rates are indicated for the reach at the outfall. This is believed to be related somewhat to the effect of ice cover. At the higher temperatures observed at the outfall, there was no ice cover. Open water was observed in the stream for the first 3 or 4 mi downstream of the outfall, with ice cover forming once again as the water temperature in the stream dropped to the

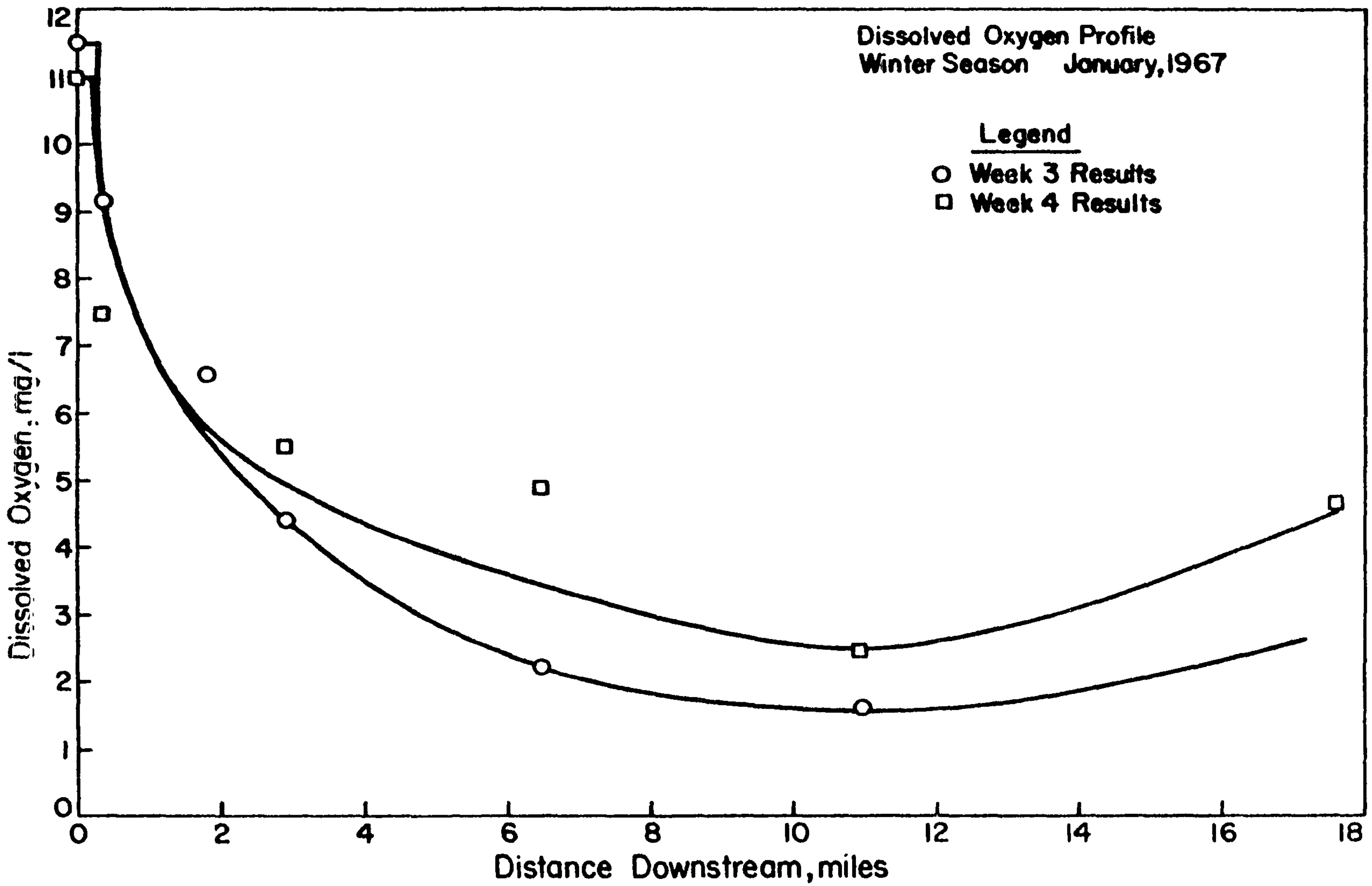

Fig. 70. Dissolved oxygen profiles for two winter season periods, daytime observations.

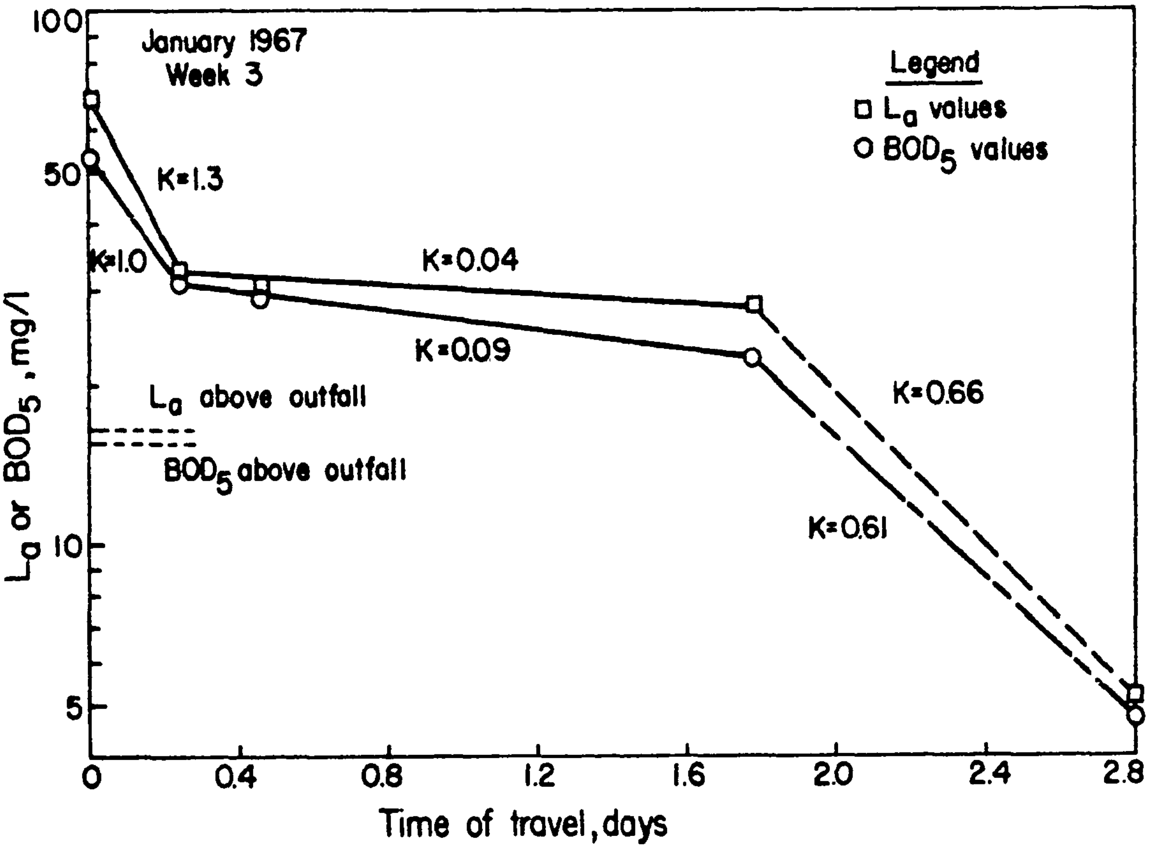

Fig. 71a. Reduction of BOD5 and L_a values for the winter season, week 3, January 1967.

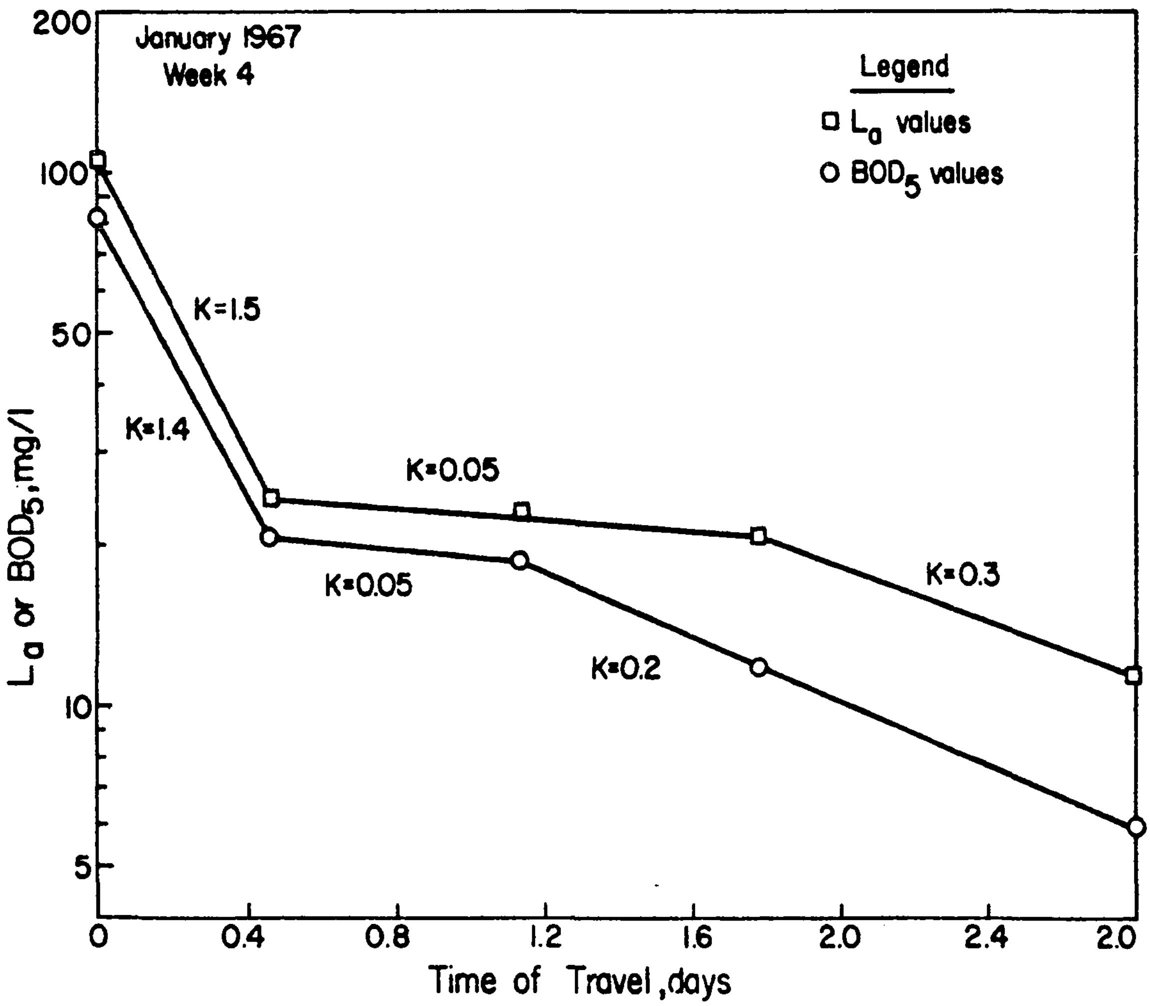

Fig. 71b. Reduction of BOD_5 and L_a values for the winter season, week 4, January 1967.

32 to 33 deg F mark. This provides an initial assimilative reach in the winter period before ice cover and a condition for no reaeration exists. Sometimes, partial open river stretches were observed as far downstream as 5 mi. Ice cover was usually encountered at all winter periods at mile 5.34. During the two sampling runs in January, at points downstream of mile 6 there would be pockets of air beneath the ice, and frequently water would not flow up out of the sample hole cut in the ice. Thus, the potential apparently exists for some reaeration in the winter season even under the ice.

F. Summary Relationships for Selected Stream Water Quality Parameters

1. General observations

The water quality field studies have provided a detailed picture of the effect of waste discharges on the receiving stream and its ecological habitat. This might also be indicative of the response that could be expected on other streams in the central part of Iowa, or those in Region III, as identified in the hydrologic studies. The field studies have served to emphasize the efforts needed to study the stream environment and to determine the fate of potential pollutants discharged to the stream. The time of travel studies provided the water movement data needed to correlate the spatial and temporal aspects of stream water quality. The temperature studies have provided an initial indication of the seasonal and diurnal trends in water temperature in the Skunk River basin, and for similar typical streams in Region III. The relationships shown to exist between air and water temperatures provide a means of estimating water temperatures from air temperature data.

The assimilative reach of the Skunk River for the Ames water pollution control plant and its related effluent discharge has been identified. It extends in the summer period from Ames to Cambridge, a distance of 10 to 12 mi. In the winter it may easily sweep farther downstream.

The several studies made of water quality effects and environmental response have resulted in the collection and analysis of a substantial amount of data. The results of the several studies were analyzed further to determine if additional relationships existed between the most important water quality parameters.

2. Relationship of the stream BOD5 load and related dissolved oxygen levels

The relationship of the observed maximum and minimum DO levels with the corresponding BOD_5 loading of the stream at the outfall station, mile point 0.37, was considered to have some merit in developing useful summary concepts. Corresponding values of BOD_5 at the outfall were determined for each detailed study period, using the natural (unpasteurized) sample data. Because this parameter, the natural water, is the one usually included in the BOD test, it was used in this summary study. The maximum daytime and minimum nighttime DO values for each study period were also summarized. These values are shown in Fig. 72. Boundary or envelope curves were drawn to represent for the assimilative reach the quantitative relationship between minimum nighttime DO and the BOD_5 load at the outfall station, and

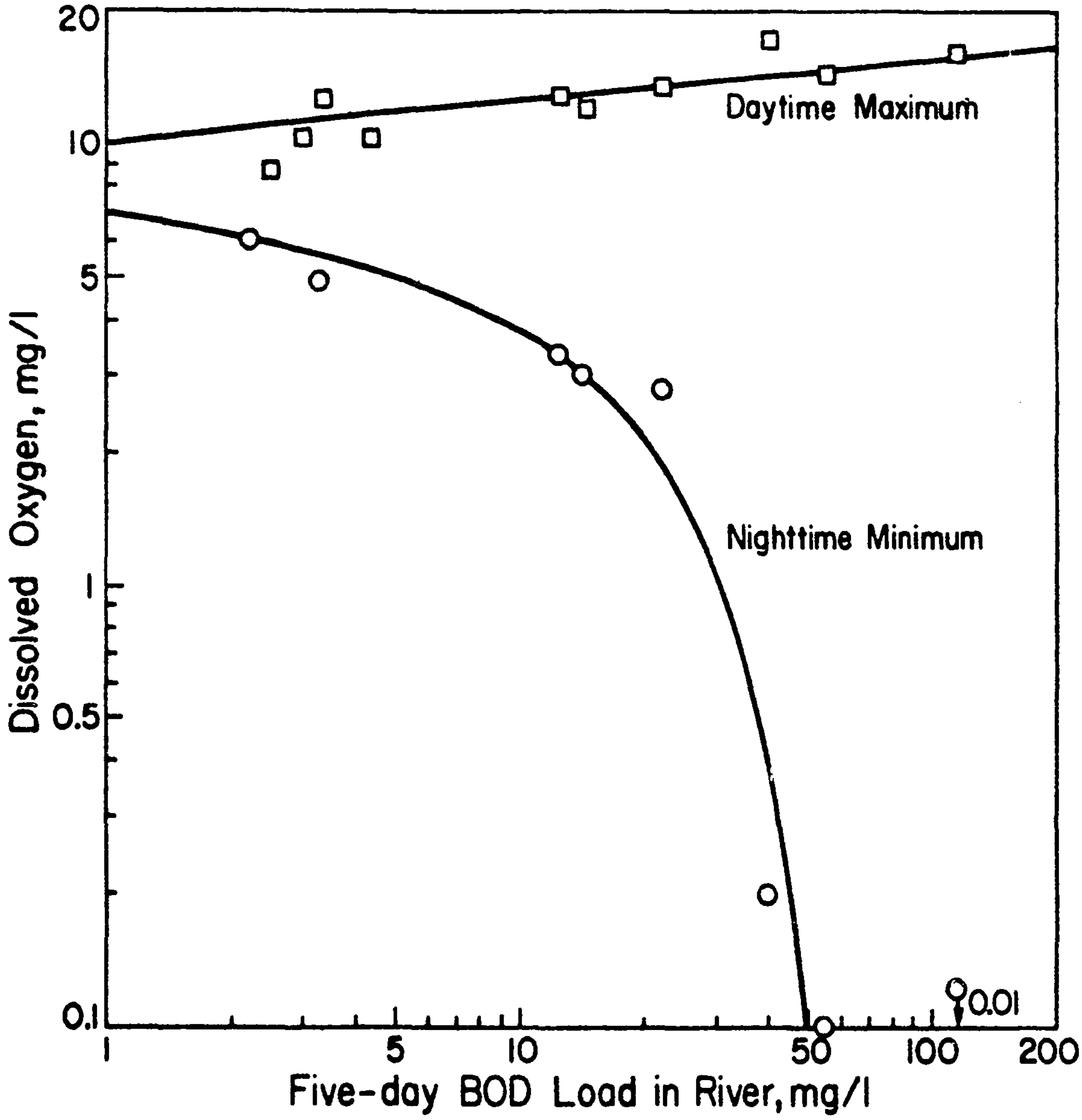

Fig. 72. Relationship of dissolved oxygen levels and the BOD_5 loading for the Skunk River.

for the daytime maximum DO as related to the same BOD_5 load.

The results in Fig. 72 show that the Skunk River is very sensitive to BOD levels and responds rapidly to increased BOD levels. The 5-day BOD in the river water (after mixing) must be limited to about 10 mg/l if a minimum of 4 mg/l DO is to be maintained in the assimilative reach. If the minimum DO level is relaxed to 3 mg/l, then the allowable BOD_5 can be increased to 15 mg/l. These are very low values of BOD_5 for normal treatment plant efficiency, if no dilution water is present. The 2:1 dilution ratio commonly experienced during the earlier part of the study, in late summer and early fall, with complete secondary treatment and 20 to 25 mg/l final effluent BOD_5, was sufficient to sustain the dissolved oxygen levels above a minimum of 3 to 4 mg/l. BOD_5 levels of 50 or more cannot be assimilated without depressing the DO level severely or completely under existing low-flow stream conditions.

The lower envelope curve also indicates that substantial tertiary treatment would be required if the minimum DO were to be increased from 4 to 5 mg/l or more. The move from 4 to 5 mg/l would require reducing the BOD_5 load in the stream from 10 mg/l to 5 mg/l. The related economic impact of achieving such reductions in BOD_5 to increase the DO by 1 mg/l can now be studied, but obviously would not be inexpensive since in all probability tertiary treatment would be required.

The upper envelope curve in Fig. 72 indicates that the maximum level of DO that might be experienced in the assimilative reach varies from 10 to 20 mg/l. Beyond a BOD_5 loading of 50 mg/l, however, the daytime surplus becomes a nighttime liability and the DO at night is depressed to a zero value. These envelope curves provide the quantitative relationships from which preliminary estimates might be made for waste treatment levels to be required in the future. However, they have the disadvantage of not indicating the full spatial extent of such minimum DO levels. If an assimilative reach were allocated to the Ames water pollution control plant, for instance, such as the 10 to 15 mi downstream of the outfall, then for a lower minimum permissible DO the BOD_5 loading could be increased somewhat without violating the desired DO levels downstream of the assimilative reach. For instance, the field studies showed that at a BOD_5 loading in the stream of 12.5 mg/l, on August 31, the minimum DO level was 3.5 mg/l but this occurred for only 4 to 4.5 mi of the total of more than 30 mi between Ames and Colfax. The DO concentration was more than 4 mg/l at all other points. A related variable to the BOD_5 level in the stream is the dilution ratio, with the DO levels remaining above 3 to 4 mg/l for ratios as low as 3:1.

These results apply primarily to summer and early fall conditions. Winter season relationships may be difficult to assess, since much depends on the existence of ice cover and its effect on the opportunity for stream reaeration. However, with partial reaeration included in the BOD_5 concepts, the curves of Fig. 72 might be extended into the winter season for preliminary design application.

3. <u>Relationship of river deoxygenation rates (K_1 values) to the stream BOD_5 values</u>

There appeared to be some indication that the river K_1 values increased as the BOD_5 loading in the stream increased. However, the K_1

data were not corrected to the reference temperature of 20 deg C, but were listed for the temperature experienced during the river sampling period.

The K_1 rates were all corrected to 20 deg C, based on the observed river temperature at the beginning of the assimilative reach (downstream of outfall after mixing). These values were then plotted versus the BOD_5 loading in the stream at the outfall. The results are listed in Table 105 and plotted in Fig. 73. A definite trend exists for K_1 to increase as the BOD levels in the stream increase. Simple regression analysis was made of the data listed in Table 105. Two analyses were made, one for all of the data and one for part of the listed data neglecting the three lowest data points of Fig. 73. The latter results were used to provide the coefficients for use in mathematically modeling this response of the stream environment. The equation for the relationship between K_1 and BOD_5 as measured at the outfall point is

$$K_1 = a(BOD_5)^b = 0.783\ (BOD_5)^{0.222} \qquad (116)$$

where

K_1 = river extraction rate for BOD removal, base 10,

BOD_5 = 5-day BOD loading for the stream at the outfall, and

a and b are constants.

The curve obtained with Eq. 116 is shown also in Fig. 73. The correlation coefficient was 0.460 for all of the data points and 0.974 for the six best points from which Eq. 116 was obtained. The results listed in Table 105 also show that the average value of K_1 is about 1.4 (20 deg C).

Table 105. Average river K_1 values and BOD_5 levels in the stream at the outfall for the several study periods

Date	K_1 at river temperature, per day	Temperature at outfall deg C	Corrected value of K_1 at 20 deg C, per day	BOD_5 at outfall, mg/l
August 3, 1966	1.18	23.0	1.03	3.3
August 11, 1966	0.50	22.8	0.44	15.8
August 19, 1966	2.10[a]	25.6	1.63[a]	39.5
August 31, 1966	2.30[a]	28.2	1.38[a]	12.5
Sept. 17, 1966	0.95	19.8	0.96	13.9
October 12, 1966	2.14	20.4	2.10	55.0
October 26, 1966	1.08	21.2	1.02	114.
January 19, 1967	1.16[b]	10.6	1.79[b]	53.0
January 23, 1967	1.44[b]	11.6	2.12[b]	82.0

[a]Average of six values for indicated date.

[b]Average of two values for indicated date.

The river K_1 values obtained in the Skunk River water quality studies agree reasonably well with the values reported for Michigan rivers by Courchaine (1963), Gannon (1966), and Purdy (1966). Values of about 1.0 were obtained in their studies. It is assumed that the smaller size of the Skunk River would produce greater values for the overall removal or extraction rates, much the same as for reaeration rates (Table 9 and 10). However, no such similar national comparison or tabulation has been prepared for K_1 values. The study results are considered to be reasonable and satisfactory for forecasting purposes.

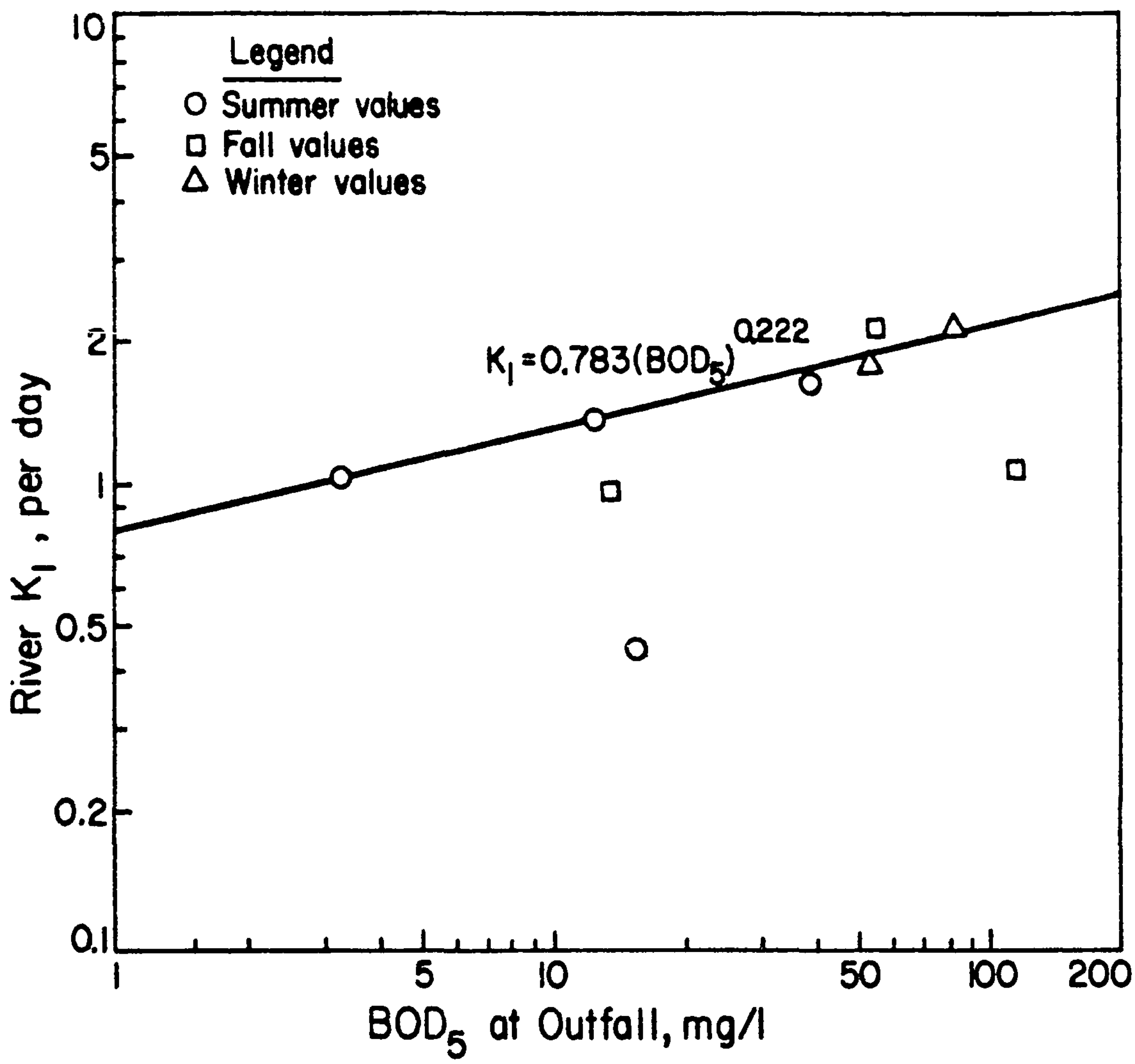

Fig. 73. Relationship of river K_1 values with BOD_5 levels in the Skunk River basin.

4. Determination of carbonaceous and nitrogenous BOD utilization ratios

a. Introduction of utilization ratios The results of the water quality studies of the Skunk River have shown the complex nature and many interrelationships which exist in the stream environment. One of the most difficult factors to evaluate appears to be the amount of theoretical nitrogenous BOD that is oxidized by nitrifying bacteria, since a portion may be used directly as ammonia by the algae and other organisms in the ecological habitat. In addition, most field studies use the 5-day period for analysis of the concentration of many non-conservative substances such as BOD. Thomas (1948) noted, however, that the ultimate values (L_a for carbonaceous and nitrogenous BOD) should be used in the mathematical models of river behavior. Therefore, in the development of methods and models for forecasting water quality, it appears desirable to use the ultimate values internally in computations but that printed results should be expressed perhaps in terms of the normal 5-day values. This would aid in interpretation and use of the results.

Three additional parameters were introduced and evaluated to accomplish the purpose outlined above. Data obtained in the comprehensive BOD studies of the August 19 and 31 period were used in this analysis. These data included the BOD_5 values obtained from the faired curves (see Appendix D) for both natural and filtered-pasteurized river samples, the corresponding L_a values as evaluated from the first-order reaction concept, and the ammonia concentrations measured at each station for the two study periods. For the purposes of this study, the three parameters are defined as

1. β, (Beta), the proportion or fraction of the theoretical BOD-N (nitrogenous BOD) based on the ammonia concentration in the stream water that is oxidized by the nitrifying bacteria, the remainder being used directly in the stream environment.

2. γ_2, (Gamma 2), the proportion or fraction of that portion of BOD-N assimilated by the nitrifying bacteria that is consumed in a 5-day period.

3. γ_1, (Gamma 1), the proportion or fraction of the ultimate carbonaceous BOD (BOD-C) that is utilized in a 5-day period.

The first parameter, β, is computed using the following equation:

$$\beta = \frac{(L_a)_{nat} - (L_a)_{fp}}{4.57\ (NH_4^+)} \qquad (117)$$

where

β = ammonia utilization fraction for oxygen demand by the nitrifying bacteria,

$(L_a)_{nat}$ = ultimate BOD, L_a, value for the natural water sample at a river station, mg/l,

$(L_a)_{fp}$ = utlimate BOD, L_a, value for the filtered-pasteurized water sample at the same station, mg/l,

$4.57\ (NH_4^+)$ = theoretical oxygen demand for complete conversion or oxidation of the ammonia to nitrates, mg/l.

The numerator is assumed to represent the maximum amount of the total nitrogenous BOD that was oxidized by the nitrifying organisms. It is based on the laboratory analyses, assuming no serious depletion of the oxygen in making the lab studies (depletion which might affect the nitrification sequence). The effect of the algae in causing variations in laboratory BOD results will be neglected in this phase of the analysis. The results thus obtained will serve as a first approximation of the river response and oxygen demand related to the ammonia discharge in the effluent of the Ames water pollution control plant. The remaining fraction, $(1 - \beta)$, will be assumed to be used directly as NH_4^+ in the stream ecological habitat.

The second parameter, γ_2, is the fraction of the BOD-N used by the nitrifying bacteria (involving β) that is used in the first 5 days, corresponding in some measure to the 5-day BOD test normally used in river and laboratory BOD studies. The factor γ_2 is computed, then, as

$$\gamma_2 = \frac{y_{nat} - y_{fp}}{(L_a)_{nat} - (L_a)_{fp}} = \frac{y_{nat} - y_{fp}}{4.57\ (\beta)(NH_4^+)} \qquad (118)$$

where

γ_2 = 5-day ammonia utilization fraction,

y_{nat} = 5-day BOD of the natural water samples, obtained from the faired curves, mg/l,

y_{fp} = 5-day BOD of the filtered-pasteurized water samples, also obtained from the faired curves, mg/l, and

the other terms were defined above.

The right-hand form of the relationship in Eq. 118 illustrates the relationship between γ_2 and β.

For the third parameter, γ_1, the relationship is computed as

$$\gamma_1 = \frac{y_{fp}}{(L_a)_{fp}} = [1 - 10^{-K_1(5)}] \qquad (119)$$

where

γ_1 = 5-day carbonaceous utilization fraction for model purposes,

K_1 = laboratory rate coefficient for the filtered-pasteurized water samples, per day, and the other terms were defined above.

The right-hand form of Eq. 119 shows that γ_1 can be computed from the K_1 value for a particular sample run, and that it must be compatible with the laboratory rate coefficient. The parameter γ_1 is introduced primarily to permit similar comparison with the carbonaceous organic wastes, as is being made for the nitrogenous material through the term γ_2.

b. Method of analysis The tabulated results of the method of determining the three parameters, β, γ_1, and γ_2 are shown in Table 106. The pertinent basic data are listed and the column designations indicate the values that were computed and combinations necessary for final determination of each of the three parameters. The differences represented in the numerator of Eq. 117 and in the denominator of Eq. 118 are listed in column 5. The theoretical nitrogenous oxygen demand, based on the ammonia concentration at each station, is listed in column 6. For stations where ammonia data had not been obtained, values were estimated from the data of adjacent stations. Computed values of β are listed in column 7, and the average value for each test period is also listed. The analysis of 5-day results is contained in columns 8 through 13. The 5-day differences, as represented in the numerator of Eq. 118, were computed and listed in column 10. Values of γ_2, $\beta\gamma_2$, and γ_1 are listed in columns 11, 12, and 13, respectively. Average values are shown also. If the computed fraction exceeded the upper bound of 1.0, it was not listed.

c. Discussion and summary The results listed in columns 7, 11, 12, and 13 of Table 106 show that reasonable values can be obtained for

Table 106. Evaluation of carbonaceous and ammonia nitrification utilization factors

Date (1)	Mile point (2)	$(L_a)_{nat}$ (3)	$(L_a)_{fp}$ (4)	Difference (5) (3)-(4)	Theoretical nitrogenous BOD, 4.57 x (NH_4) (6)	β (7) (5)/(6)	$(BOD_5)_{nat}$ (8)	$(BOD_5)_{fp}$ (9)	Difference (10) (8)-(9)	γ_2 (11) (10)/(5)	$\beta\gamma_2$ (12) (10)/(6)	γ_1 (13) (9)/(4)
Aug. 19	0.38	46.10	33.10	13.00	36.1	0.36	39.5	27.1	12.4	0.95	0.34	0.82
	0.93	33.75	25.39	8.36	28.8	0.29	29.6	21.0	8.6	-[a]	0.30	0.83
	1.80	20.77	11.35	9.42	17.4	0.54	16.5	9.20	7.3	0.78	0.42	0.81
	2.93	14.53	12.10	2.43	8.7	0.28	10.65	7.02	3.63	-[a]	0.42	0.58
	5.34	9.28	8.93	0.35	9.6	0.04	8.00	4.29	3.71	-[a]	0.39	0.48
	8.94	13.15	11.58	1.57	13.7	0.11	9.40	6.52	2.88	-[a]	0.21	0.56
						Avg.(0.27)				Avg.(0.86)	Avg.(0.35)	Avg.(0.68)
Aug. 31	0.38	21.48	7.45	14.03	25.6	0.55	12.45	5.80	6.65	0.47	0.26	0.78
	1.80	10.04	3.66	6.38	6.0	-[a]	5.40	2.55	2.85	0.45	0.48	0.70
	2.93	11.22	3.80	7.42	5.7	-[a]	4.80	2.15	2.65	0.36	0.47	0.57
	5.34	6.18	3.98	2.20	5.5	0.40	5.20	3.02	2.18	0.97	0.40	0.76
	8.94	5.68	3.34	2.34	4.6	0.51	4.55	2.67	1.88	0.80	0.41	0.80
						Avg.(0.50)				Avg.(0.61)	Avg.(0.40)	Avg.(0.72)

[a]Computed value exceeded upper bound of 1.0.

the selected parameters. The average values of γ_1 for the two periods are 0.68 for the August 19 data and 0.74 for the August 31 data. The higher values range from 0.76 to 0.83, with a high value average of about 0.80. This corresponds to a laboratory K_1 rate of 0.14 to maintain equivalency in Eq. 119.

The results for β and γ_2 are less consistent. To assist in the evaluation, the product $\beta\gamma_2$ was also computed and listed in column 12. The results show very good agreement for the $\beta\gamma_2$ values, with an average value of 0.35 for the August 19 data and 0.40 for the August 31 data. This means that 35 to 40% of the oxygen demand for the theoretical nitrogenous BOD is required in the first 5 days. Values for this parameter ranged from 0.21 to 0.48, about a two-fold range.

The pertinent values of β gave an average of about 0.3 for the August 19 data, but with several high γ_2 values. For the August 31 data, the average β value was 0.50, with some high results greater than the upper bound of 1.0 not evaluated. The average value for γ_2 was 0.6.

Although good comparison between the two periods was not obtained, the range of values provides some quantitative information about the nitrification phenomena which heretofore has not been evaluated in river studies. The range of values of β are especially pertinent to water quality forecasting, with the results showing that, in general, less than 50% of the ammonia must be nitrified by the nitrifying bacteria. This reduces considerably the stress placed on the oxygen resource of the stream environment, with a 50% reduction being the minimum relief which might be expected.

Some importance must be placed also on the fact that the August 19 study period took place during the simulated primary effluent phase of plant operation. The samples probably represent, at the very least, the effects which might be expected in a moderately polluted stream. Less ammonia nitrification could be expected under these conditions of increased organic loadings, lower DO levels, etc., as indicated by the lower β values for this period. Conversely, the August 31 study period was conducted during the complete secondary treatment phase. The average β value of 0.50 can therefore be assumed to apply to more normal effluent and stream conditions. For this late August run, the Y_2 values ranged from 0.36 to 0.47 in the reach just downstream of the outfall, with the remaining and highest values being obtained at the two downstream locations where clean water conditions again predominated.

A summary of pertinent values of these three selected parameters was prepared and the values are listed in Table 107. The average values listed can be used in developing a mathematical model for simulating the observed levels of water quality in the study stream, and in forecasting future water quality levels. The average values of β that are listed, 0.4 to 0.5, can be used with the range of values of Y_2, 0.5 to 0.7, to produce the average results obtained for the product of the two, βY_2, of 0.3 to 0.4.

5. Preliminary analysis of stream reaeration factors

a. Indirect method of analysis The complexity of the stream environment and its response to effluent loads and nutrients makes direct evaluation of additional relationships difficult if not

Table 107. Summary values for carbonaceous and nitrogenous utilization factors for the Skunk River

Item	Parameter	General range of values	Average values for forecasting purposes
1.	Y_1	0.70 - 0.85	0.80 - 0.85
2.	Corresponding K_1, laboratory values	0.11 - 0.17	0.14 - 0.16
3.	βY_2	0.2 - 0.5	0.3 - 0.4
4.	Y_2	0.4 - 0.8	0.5 - 0.7
5.	β	0.3 - 0.6	0.4 - 0.5

impossible. In some studies (Churchill et al., 1962) assumptions or laboratory experiments regarding the photosynthesis and respiration rates of algae permitted additional evaluation of the river reaeration rate, K_2. In other studies (O'Connell and Thomas, 1965), assumptions of stream reaeration rates were used to evaluate the net algal contribution to the dissolved oxygen resource. However, with the added effect of nitrification of the nitrogenous BOD and the boundary additions of carbonaceous BOD, direct analytical studies do not appear practical or possible at this time. Therefore, more indirect methods were introduced to provide some estimate of the ability of the study stream to reaerate through the two phenomena listed, atmospheric reaeration and algal contributions.

b. Computed stream reaeration factors for the Skunk River The stream reaeration capability of the Skunk River was evaluated using relationships developed in various parts of the nation and published in the literature. These included the information, data, and mathematical models discussed in Vol. I, in the section devoted to stream reaeration factors. Equations 37, 40, and 41 were selected for analysis of reaeration rates for the study stream. These equations include the mean depth of flow and the stream velocity as the parameters influencing the magnitude of the reaeration rate. The mean depth of flow, H, can be best expressed as a function of discharge, permitting the the variable K_2 to be expressed eventually in terms of the stream discharge, in a form similar to Eq. 42. The average stream velocity, U, was evaluated through the dye tracer studies, and is expressed by Eq. 114.

c. Depth-discharge relationship for the Skunk River Stage-discharge data were obtained for the Skunk River at the gaging station located below the confluence of Squaw Creek. This station was selected as the reference station for the assimilative reach. Data were obtained from the U.S. Geological Survey regarding stage-discharge, measurement notes recorded during discharge determinations, and miscellaneous depth-discharge data obtained during the dye tracer studies. These data were tabulated and analyzed for uniformity and observed trends, and plotted in Fig. 74. The stream depth shows a characteristic increasing trend with the discharge, but with a definite break observed at about 100 cfs. Additional analysis was made to confirm that this break occurred at the discharge at which the main channel width was fully covered but at shallow depths of flow. At discharges greater than 100 cfs, the increase in stream width was very small, with the

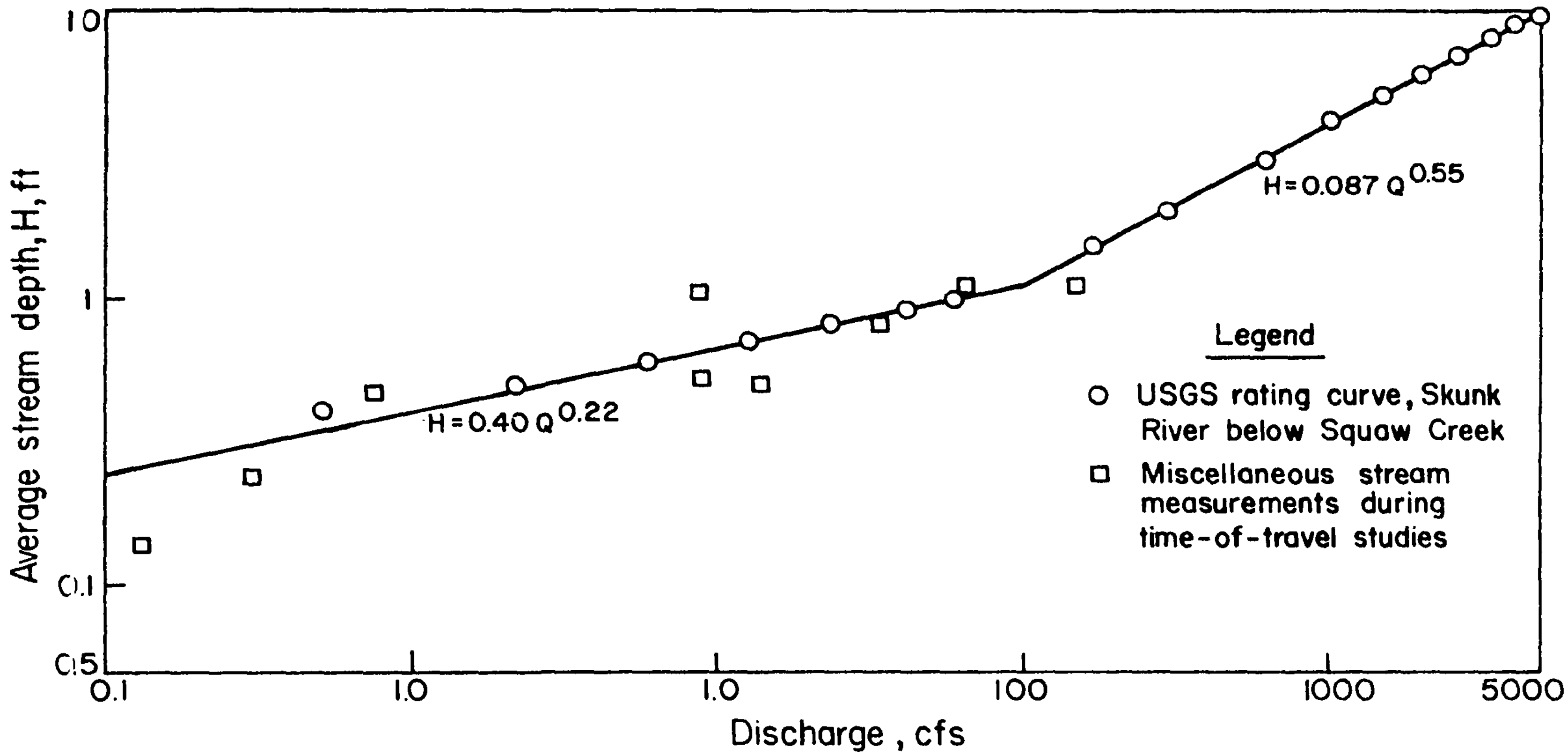

Fig. 74. Average stream depth versus discharge in the Skunk River at Ames, Iowa.

increase in cross-sectional area being derived from depth increases only. For lesser discharges, the stream consists of braided channels, riffles, pools, etc., that occur at random. The Skunk River, a dredged channel from Ames to the Keokuk-Mahaska County line, is a wide but shallow stream at low-flow stages.

The observed two-stage relationship is acceptable and reasonable for the known channel characteristics. The mathematical models expressing the two limbs of the curve shown in Fig. 74 are

$$H = 0.40\ Q^{0.22} \qquad Q \leq 100 \qquad (120a)$$

$$H = 0.087\ Q^{0.55} \qquad Q > 100 \qquad (120b)$$

where

H = average stream depth in the assimilative reach, ft, and

Q = total stream discharge, cfs.

The relationship shown for the larger discharges, Eq. 120b, follows the general relationships noted by Langbein and Durum (1967), as indicated previously in Tables 9 and 10.

d. <u>Relationship of the stream reaeration rate, K_2, and discharge, Q</u>

The reaeration coefficient, K_2, can be correlated with stream discharge, Q, using the average stream velocity as expressed in Eqs. 114a through 114d, and the average stream depth as expressed in Eq. 120. As noted above, Eqs. 37, 40, and 41 were selected for comparative analysis. A digital computer program was written to evaluate K_2 for the three selected models, the O'Connor-Dobbins model (Eq. 37), the TVA model (Eq. 40), and the U.S.G.S. model (Eq. 41). Values of the average stream velocity were obtained using Eq. 114c. This utilizes the half-hydrograph area and provides a stream velocity that is about the magnitude of the centroid value. It was considered to be the most representative average velocity of the stream. The computer program included a routine for obtaining the geometric mean of the results of the three selected mathematical models. Computer output included the K_2 values for each of the models, and the log-average value.

The results were fairly compatible, considering the variations which might be expected in applying theoretical analysis requiring simplifying assumptions and empirical relationships. The results are shown in Fig. 75. The O'Connor-Dobbins model provided the highest values of K_2 in the low discharge range, 10 to 100 cfs. Values ranged from 7.43 to 5.35. The U.S.G.S. model provided the lowest results, varying from 2.95 to 3.54, an increasing trend. The TVA model provided results nearer to the O'Connor-Dobbins model, varying from 5.11 to 5.20, again exhibiting a small increasing trend. The mean depth relationship in this discharge range (Eq. 120a) is very flat and indicates little change in depth as the discharge increases toward the 100 cfs level. This encourages a high rate of reaeration since the surface area is large and the depth small. Once the flow extends from bank to bank, the reaeration coefficient decreases in the characteristic trend noted previously in the review of the U.S.G.S. techniques. For discharges from 100 to 1,000 cfs, the three models are in more complete agreement, with the derived relationships crossing in this range of discharge. Values decrease from a magnitude of 3.5 to 5.2 downward to a range of 1.24 to 1.56 at a discharge of 1,000 cfs.

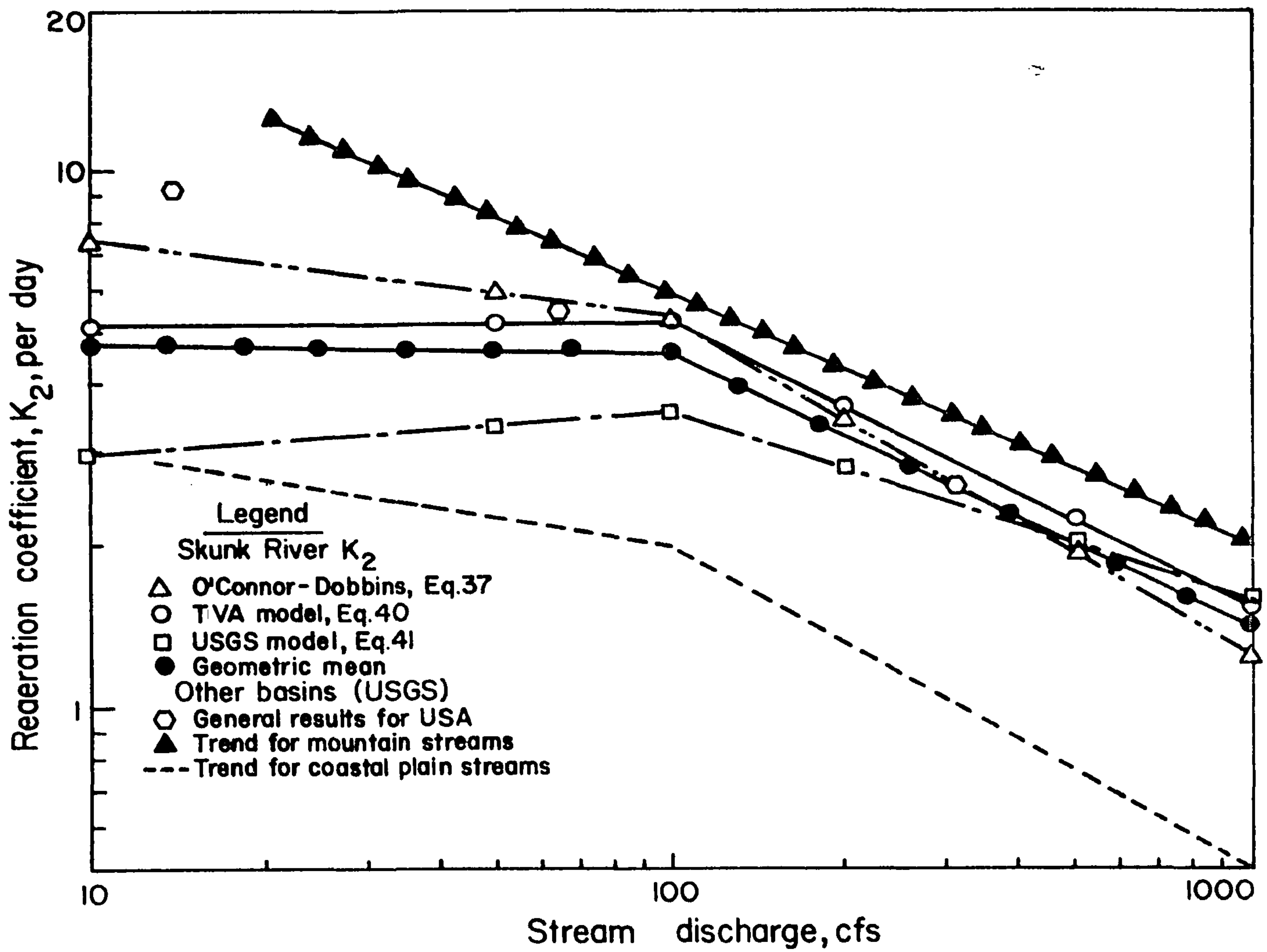

Fig. 75. Computed relationships of the reaeration coefficient and stream discharge for the Skunk River at Ames, Iowa.

The geometric mean of the three mathematical models was adopted for use in additional water quality analytical studies, and this average relationship is included also in Fig. 75. The mathematical model for the stream reaeration coefficient in the assimilative reach of the Skunk River is expressed (K_2, base 10) as

$$K_2 = 5.00\ Q^{-0.0185} \qquad Q < 100 \text{ cfs} \qquad (121a)$$

$$K_2 = 49.7\ Q^{-0.517} \qquad Q \geq 100 \text{ cfs} \qquad (121b)$$

e. Discussion and summary   Equations 121a and 121b were used in a digital computer program to provide K_2 values for a wide range of discharges, from 1 to 2,500 cfs. The results, as indicated by the curve in Fig. 75, show that the reaeration coefficient has a practically constant value in the discharge range 1 to 100 cfs, varying from 5.0 to 4.6 in this range. The decrease in K_2 values for discharges greater than 100 cfs follows the previously discussed trend presented by Langbein and Durum (1967). For the Skunk River, values decrease from 1.4 at flows of 1,000 cfs to 0.87 at flows of 2,500 cfs.

The mathematical model for K_2 obtained in this analysis gives results that are in good agreement with Eq. 42, which was developed by the U.S.G.S. for midwestern, large size streams. This indicates that Eq. 42 might be extended downward to streams having a mean discharge of about 100 to 200 cfs. The exponent for Q has an average value of - 0.5, with the constant being in the range of 50 to 60. The average relationship that could serve as a first approximation for the reaeration coefficient for all intermediate and large size streams in the midwest (streams having average depths of flow greater than 1 ft and discharges in excess of 100 to 200 cfs) would be

$$K_2 = 55\ Q^{-0.5} \tag{122}$$

This mathematical model provides a means of estimating the reaeration coefficient in the absence of other more precise data for streams in the midwest. It should be noted that all of the computed values are much higher than those values customarily published in texts. The higher values are applicable to smaller streams seldom studied in the early days of pollution control. The values appear to be reasonable, in view of the turbulent nature observed in the small and intermediate size streams and in view of their relatively shallow depths and rapid mixing.

Values of the self-purification factor, ($f = K_2/K_1$), which were discussed previously, are not changed appreciably, however. The deoxygenation coefficient, K_1, for the Skunk River was expressed in quantitative terms in Eq. 116, and produces values in the range 0.8 to 2.1 (an average of 1.4) for BOD_5 values of 1 to 100 mg/l. Therefore, in the range of 1 to 100 cfs, the f ratio varies from about 2.2 to 6.0. For the average K_1 value of 1.4, the f ratio varies from 3.0 to 3.5. Therefore, the values selected previously in the hydrologic study portion of this report receive additional confirmation through this analysis.

6. Initial determination of the algal oxygen contribution

A first approximation of the daytime rates of net photosynthetic oxygen production and nighttime respiration rates was established through careful review and analysis of selected relationships and data of the field water quality studies. Both the diurnal dissolved oxygen in the stream at the gaging station above the outfall and the dissolved oxygen profile results were used in this analysis. The former served as a means of obtaining an estimate of the background or "clean stream" rates of algal oxygen activity. The latter data were used to determine the minimum rates of net photosynthesis (P-R) in the assimilative reach downstream of the outfall.

a. Background rates of photosynthesis and respiration The diurnal variations in dissolved oxygen, Fig. 58, were used to evaluate the background level of photosynthetic activity of the algal environment in the reach upstream of the outfall of the Ames water pollution control plant. Approximate solutions were obtained by neglecting the BOD uptake for the low BOD concentrations observed in this reach. Lag effects between temperature and DO levels relative to saturation DO levels were also neglected. Because the carbonaceous and nitrogenous BOD values are quite low in this "clean stream" reach (less than 3 mg/l in the early summer and less than 5 to 6 mg/l in the fall), this assumption of negligible BOD uptake offers a unique but reasonable opportunity to compute values of (P-R) and R at the initial sampling station area. Applied on a diurnal basis, the differential equation for the dissolved oxygen deficit as expressed in Eq. 43 simplifies to

$$\frac{dD}{dt} = - rD - (P\text{-}R)(24) \qquad (123)$$

where

D = dissolved oxygen deficit, mg/l,

t = time, days,

r = reaeration coefficient, base e, per day, and

$(P-R)$ = net photosynthesis rate, mg/l/hr, with (24) being hours per day.

If the dissolved oxygen values are selected at the peak supersaturation concentration of DO in the daytime, and at the minimum DO level at night, then $dD/dt = 0$. This is observed in Fig. 58 for one of the study periods, and the values are indirectly included in the isopleth diagrams of Figs. 65, 66, and 68. If the relationship, $D_p = C_s - C_p$, is introduced in Eq. 123, then the net rate of photosynthesis is given by

$$(P-R) = \frac{1}{24} r(C_p - C_s) \tag{124a}$$

and the nighttime respiration rate is given by

$$R = \frac{1}{24} r(C_s - C_m) \tag{124b}$$

where

C_s = saturation value of DO for the temperature observed in field, mg/l,

C_p = DO concentration observed at the peak of the diurnal cycle, mg/l,

C_m = DO concentration observed at the minimum DO level of the diurnal cycle, mg/l, and

other terms were defined previously.

Solutions of Eqs. 124a and 124b were obtained for the various study periods in which either diurnal or DO profile data were available. Values of C_p, C_m, the related water temperatures, and discharge were tabulated for each of the pertinent study periods. Values of r were obtained using Eq. 121. Values of C_s were computed with Eq. 32, correcting for the elevation difference between mean sea level and the stream at Ames. The results of this analysis are listed in Table 108 for the daytime net photosynthesis, P-R, the nighttime respiration, R, and final results for P and P/R ratios.

The values of (P-R) varied from 0.4 to 2.0, with an average of 1.0 mg/l/hr. The July value is relatively low compared to the others. This is believed to be due to the very clean stream environment which was observed at the high base flows experienced following the June flood period. The growth and adherence of algae was slow during this period. The high August (P-R) value may be due to a combination of high temperatures (reaching 85 deg F on most days) and seasonal growth trends of the algal environment. The remaining values range from 0.8 to 1.3, indicating that the net photosynthesis rate was approximately constant for late summer and fall conditions.

Respiration rates, R, show an increasing trend through the summer and fall seasons, as the results in Table 108 indicate. Values ranged from 0.8 to 2.1, with an average of 1.5 mg/l/hr. The lowest values were computed for the early summer season, and the highest values were obtained in the late fall period. This trend is attributed to the continued growth of the algae during the summer and fall season. The greater amount of growth of the attached varieties, at the boundary, might logically result in increased respiration rates as the year progressed, in the absence of flood periods which might have flushed out the stream system.

Table 108. First approximation values for algal photosynthesis rates for the Skunk River upstream of the assimilative reach at Ames

Field study period, 1966	Stream discharge, cfs	Daytime values for (P-R) Peak DO concentration, mg/l	Temperature at peak, deg C	Computed (P-R), mg/l/hr	Nighttime values for respiration, R Minimum DO concentration, mg/l	Temperature at minimum, deg C	Computed R, mg/l/hr	Net results Photosynthesis rate, P, mg/l/hr	P/R ratio
July 11-12	100.	7.6	32.	0.4	6.0	27	0.8	1.2	1.5
Aug. 2-3	15.	9.4	25.	0.8	5.8	19	1.5	2.3	1.5
Aug. 17-19	11.	9.9	28.	1.3	6.5	22	1.1	2.4	2.2
Aug. 30-31	9.0	10.6	30.	2.0	5.8	22	1.6	3.6	2.3
Sept. 6-7	5.7	9.4	25.	0.8	6.7	18	1.2	2.0	1.7
Sept. 28-29	1.2	11.1[a]	15.	0.8	5.7	15	1.5	2.3	1.5
Oct. 6-7	0.1	11.7	19.	1.3	5.3	10	2.1	3.4	1.6
Oct. 24-25	0.8	11.9	17.	1.1	5.4	8	2.0	3.1	1.6
				Avg. 1.0			Avg. 1.5	Avg. 2.5	Avg. 1.7

[a]Correction applied to observed peak value because cold front and heavy cloud cover moved into area during field study period.

If the values of (P-R) remain fairly constant, as reported above, and the values for respiration, R, increase during the summer and fall seasons, then the gross photosynthesis rate, P, should also increase during the year. This trend, as indicated by the data in Table 108, is not too evident. Values do range from 1.2 in July to 3.1 to 3.4 mg/l/hr in late fall, but fairly high values are obtained also in the midsummer period. The average value for P is 2.5 mg/l/hr. The values of the P/R ratio show a different trend. The values increase from 1.5 in early summer to more than 2 in August, then decrease somewhat in the early and late fall period. The average value of P/R is 1.7.

These results, when compared to the values discussed in the review part of this study, give respiration and net photosynthesis rates somewhat higher than those obtained in other river studies and reported in the literature. The P/R ratios are somewhat lower in magnitude. Some of the difference may be in the value of saturated DO concentration used in the analysis. If the actual saturated level of DO is lower than assumed, then the values of respiration, R, would be lower, and the values of (P-R) for daytime analysis would be higher. This might provide results more in accordance with results of other studies. However, such differences are not easily computed or estimated, and additional analysis was considered beyond the scope of the project purposes. The values obtained in this analysis provide at least a first approximation for application in water quality simulation studies. Obviously, the solutions for (P-R) and R obtained using Eqs. 124a and 124b depend also on the accuracy of the value of reaeration rate, r. Adequacy of these several approximations will depend on correlation of the results of simulation studies with observed water quality parameter levels.

b. <u>Approximate minimum (P-R) values for the assimilative reach</u> An analysis was made to determine the magnitude of the net photosynthesis rates in the assimilative reach during the various study periods. The slopes of the DO profile curves, as shown in Figs. 59 and 62 for four of the study periods, provide a means of computing an approximate minimum value of (P-R) in the assimilative reach for the daytime period. If the slope of the DO profile is based on time of travel instead of distance, and the magnitude of the slope is computed at the DO concentration at saturation, then the differential equation for the dissolved oxygen deficit can be transformed to yield

$$(P-R) = \frac{1}{24} (\frac{dC}{dt} + \text{carbonaceous BOD uptake} + \text{nitrogenous BOD uptake}) \qquad (125)$$

where

(P-R) = net photosynthetic activity, mg/l/hr,

C = DO concentration at any time t in the spatial context, mg/l,

t = time, days, and

the other uptake rates are in accordance with Eqs. 43, 62, 65 and 70.

Equation 125 indicates that the net rate of photosynthesis will be at least as great as the slope of the DO profile curve at saturation DO levels, for which the term (rD) is obviously zero. Therefore, the

(P-R) values for the study periods for which data were available were computed. The results for seven such periods are listed in Table 109. Values of the minimum net photosynthesis rate for the assimilative reach range from 0.7 to 3.0 with an average of 1.3 mg/l/hr. If the one high value of 3.0 mg/l/hr is neglected (which occurred during one of the primary effluent study periods), then the remaining values provide an average value of 1.05 mg/l/hr. These rates are similar to the values obtained for the reach upstream of the outlet, in the "clean stream" environment.

The results do not indicate a material increase in (P-R) values in the assimilative reach. However, the values obtained for the assimilative reach are minimum values; therefore, the actual (P-R) values will be greater and it can be concluded that the values of (P-R) will increase from the background levels. The magnitude of the increase can be explored on a trial and error basis during the development and verification phases of water quality simulation studies.

Additional review was made of the articles previously discussed and of the general trends observed in the reach upstream of the outfall to develop seasonal values representing the base level of algal activity for use in simulation and forecasting studies. Although considerable judgment is inherent in the selection of the base level values, they serve at least as a first approximation for use until future research efforts can provide more meaningful data. The values selected and used in simulation studies are tabulated in Table 110. The values selected represent a drought period concept, during which the algal environment continues to grow and increase in activity. The ratios of P/R reflect

Table 109. Computed minimum net photosynthesis rates for the assimilative reach of the Skunk River downstream of Ames

Field study period, 1966	Slope of DO profile at saturation DO, dc/dx, mg/l/mile	Average stream velocity, mph	Least value of (P-R), mg/l/hr
Aug. 2-3	2.4	0.45	1.1
Aug. 17-19	7.2	0.42	3.0
Aug. 30-31	2.2	0.41	0.9
Sept. 6-7	2.0	0.36	0.7
Sept. 28-29	4.2	0.30	1.3
Oct. 6-7	4.6	0.29	1.3
Oct. 24-25	3.5	0.28	1.0
			Avg. 1.3

the decrease in solar energy as fall approaches, but with continued high respiration rates from algal growths produced under summer conditions. Winter condition values are much more speculative, since few data were obtained during this period. The nature of algal activity within the stream habitat at low temperatures should be studied in depth to provide more meaningful data. The values selected reflect the good dissolved oxygen level observed in the study period, and the lack of complete deoxygenation of the stream from both BOD uptake and algal respiration under a fairly heavy ice cover. The thickness of ice ranged between 6 to 12 in. during the winter observation period.

c. Summary remarks The average relationships developed in this section illustrate the results that can be obtained through

Table 110. Base levels of algal photosynthesis rates adopted for forecasting purposes, Skunk River at Ames, Iowa

Month	Base level value for indicated parameter: Respiration, R, mg/l/hr	Photosynthesis, P, mg/l/hr	Net photosynthesis, P-R, mg/l/hr	P/R ratio
July	0.8	1.2	0.4	1.5
August	1.0	2.0	1.0	2.0
September	1.5	2.7	1.2	1.5
October	2.0	3.0	1.0	1.6
November	2.0	2.8	0.8	1.4
Winter:				
(1) Open water	1.0	1.4	0.4	1.4
(2) Thin ice	0.5	0.5	0.0	1.0
(3) Snow (and thick ice)	0.2 to 0.5	0 to 0.1	- 0.2 - 0.4	0.0 to 0.2

comprehensive analysis of the data obtained in water quality field studies. These relationships provide a basis for developing a mathematical model for simulating the water quality levels observed in the field studies and the related response of the stream to effluent discharge. These relationships include the time of travel versus discharge formulations, the water and air temperature correlations and seasonal levels, and other hydrologic variables. The water quality relationships include the allowable dissolved oxygen levels versus BOD_5 loadings in the stream, the relationship of river K_1 values versus the BOD_5 values, and the concepts introduced in the form of the three parameters, γ_1, γ_2, and β. Reaeration factors for atmospheric reaeration and algal effects also have been determined. These results, in conjunction with the projection of future waste loads and concentrations of selected potential pollutants summarized in the previous part, provide the input data and quantitative control relationships for a proposed simulation model.

XIII. A MATHEMATICAL MODEL FOR SIMULATING STREAM BEHAVIOR

A. General

The water quality studies of the Skunk River reported in the previous chapter have quantified the response of the stream environment to the discharge of effluents from the Ames water pollution control plant. The dissolved oxygen profile data and associated levels of other water quality parameters have confirmed the existence of a finite reach where the effluent is assimilated by the stream and clean water conditions are once more restored. The organic loading and nutrient concentrations (primarily nitrates and phosphates) have provided an abundance of food for the ecological habitat in the stream environment. The ecological habitat has responded by the growth of algae, primarily of the attached varieties.

In the assimilative reach, the stream environment rapidly utilizes the organic matter and nutrients contained in the Ames effluent. This has resulted in the production of a substantial supersaturation concentration of dissolved oxygen in the daytime, but also has created a respiration liability in the nighttime. Downstream of the assimilative reach, the stream environment returns to the same relative clean stream environment that exists upstream of the municipality. This is observed primarily in the return of water quality parameters to the levels measured upstream of the plant outfall. During the winter period, however, the brief observations which have been made indicate that the low water temperatures slow the assimilative rate, and some substances such as ammonia may be oxidized and/or assimilated much more slowly.

The water quality studies have demonstrated conclusively that the influence of the algal growths must be included in analytical studies. Mathematical models for water quality forecasting (on a temporal and/or spatial basis) will not provide meaningful solutions unless the algal influence can be included therein. In addition, nitrification of some portion of the ammonia load, oxidation of the carbonaceous organic material, and the effect of boundary BOD additions (at the channel bottom or the air-water interface) must also be considered. The low level of suspended solids in the Ames water pollution control plant effluent, even during the period when a simulated primary effluent was discharged to the stream, provides evidence that the sludge load problem can be neglected. If raw sewage containing the settleable solids were involved, then the sludge load effect would have to be considered.

Many problems were encountered in making the water quality field studies that are seldom mentioned in the literature and almost never included in the more simple mathematical models presented in most references and textbooks. These additional factors are (1) the increasing stream discharge in the downstream direction which provides additional dilution water, (2) the longitudinal dispersion of solutes or pollutants as indicated in the dye tracer studies, (3) the diurnal temperature changes and their associated effects on the saturation dissolved oxygen levels, (4) the winter effects when the water surface near the outfall is not yet frozen because of the higher effluent temperatures, and (5) seasonal influences of the air and water temperatures related to the occurrence of low-flow discharges.

The development of a mathematical model which can simulate the water quality in the Skunk River is described in this chapter. Once an adequate simulation model is developed, forecasts can be made for future conditions under selected levels of hydrologic influences and municipal growth patterns. The concept of modeling the dissolved oxygen profile envelope curves shown in Figs. 59 and 62 (reflected also in the extreme values of the isopleth diagrams of Figs. 65, 66 and 68) and the assimilation of the potential pollutants in the environment will be discussed first. Development of the appropriate response equations for the proposed mathematical model will be presented as the second topic. Incorporation of the mathematical model in a comprehensive digital computer simulation model will then be described. Confirmation and verification of the simulation model using the results obtained in the field water quality studies will be presented next. Following the simulation study, the status of water quality as of 1970 will be forecast. The last section will be devoted to forecasts (or predictions) of the stream response to future loading conditions, using a 1990 design level. These forecasts will be made for several alternative measures for improving or enhancing stream water quality, including the trickling filter and activated sludge secondary treatment processes, low-flow augmentation using the proposed Ames Reservoir, and a simulated tertiary lagoon.

B. Concepts of the Dissolved Oxygen Profile Envelope Curves

The Skunk River is a medium size Iowa stream with poor low-flow characteristics. Its response to effluent discharge has revealed the complexity of the problem of modeling the natural environment. Both spatial and temporal variations of water quality are involved in the real world environment, but in most applications of mathematical theory only the spatial effects are considered. The related temporal effects are considered in these instances (see Fig. 3) through the assumption of steady-state conditions ($x = Ut$). O'Connor (1967) included the diurnal effect of photosynthesis, as discussed in a previous part of this study, using a half-wave sine function. The quantity (P-R) was considered constant for the entire reach of stream. However, the increase in the photosynthetic process in an assimilative reach, as observed in the Skunk River field water quality studies, is not included in the O'Connor development.

No one published mathematical model could be applied to the observed results of the water quality field studies. A complete and precise mathematical model of the observed relationships must include the following:

1. Longitudinal dispersion phenomenon, as evidenced by the dispersion of the fluorescent dye tracer Rhodamine BA. The figures in Appendix B illustrate this effect.

2. Temporal or diurnal changes in several (or all) water water quality parameters, with the more important variations noted in:

    a. Temperature of air and water.

    b. Saturated values of dissolved oxygen.

c. Actual dissolved oxygen concentrations.

d. Dissolved oxygen deficit.

e. Algal photosynthesis and respiration cycle.

3. Spatial changes in several water quality parameters, superimposed on the temporal or diurnal variations.

a. Values of photosynthesis (P), respiration (R), and net photosynthesis (P-R), as evidenced in the assimilative reach. Figures 59 and 62 illustrate this effect in creating a spatially varied dissolved oxygen profile.

b. Increase (or decrease in infrequent drought periods) in stream discharge in the downstream direction, both from groundwater and smaller tributaries.

c. Change in the temperature of the stream caused by the effluent being at a different temperature than the stream, and with the temperature after mixing subsequently returning to the base temperature of the stream (which itself varies diurnally).

4. General assimilation of other potential pollutants of the nonconservative category. These include:

a. Carbonaceous and nitrogenous BOD.

b. Coliform bacteria, and related disease organisms.

c. Various forms of nitrogen (ammonia, organic, nitrite, nitrate).

d. Phosphates and any other substances considered to be nutrients.

e. Other pollution-indicator water quality parameters.

5. Additional inflow or addition of pollutants at the boundary, or from tributary streams. The bank load category of Eqs. 65 and 66 is an example.

Some of these factors were included in the composite mathematical model introduced previously in the form of Eq. 74. However, additional consideration of the algal influence is needed before this model can be useful in predicting stream response to a pollutional load. The form of

Eq. 74 implies steady-state conditions on a temporal basis and diurnal effects are not considered. O'Connor's models probably offer the greatest opportunity for application, if the integral relationships between spatial and temporal aspects can be evaluated. However, he provides no indication how the dispersion phenomena should be included in this approach, nor is the algal relationship adequate for the observed conditions.

The development of a complex theoretical mathematical model which would include all of the above listed variables was considered beyond the scope of this initial study of water quality relationships in Iowa streams. Such a complex model would require, for example, knowledge of diurnal variations in all of the water quality parameters. These variations have been studied for relatively few of the potential pollutants observed in the Skunk River water quality research program. Inclusion of the dispersion phenomena will require advanced mathematical concepts and additional stream verification studies for high, intermediate and low river stages. The low-flow riffle-pool sequence will vary from the more uniform flow characteristics with higher flows in the main channel, with related vertical, lateral, and longitudinal dispersion aspects. Such a complex model probably should involve the truckload approach of Velz (1958). This involves sending an input of effluent discharge down the stream on, say, an hourly incremental basis, following it temporally and spatially and permitting assimilation, dispersion, dilution, etc. of the appropriate water quality parameters and/or potential pollutants.

These complexities led in this study to a simplified approach for the development of a water quality simulation model. It was hypothesized that development of a mathematical model which could simulate the observed response of the stream environment would be adequate within bounds for forecasting future water quality levels in the reach of the Skunk River studied. The objective of the simulation was to reproduce the daytime maximum dissolved oxygen (DO) profile and the nighttime minimum dissolved oxygen profile, as observed in Figs. 59 and 62 for four of the study periods. The simulation of dissolved oxygen, and the transport, dilution and/or assimilation of the other observed water quality parameters should be included in the model. If the results of applying such a simulation model were adequate and satisfactory, then the daily average value of the selected water quality parameters could be approximated as the arithmetic average of the respective maximum and minimum values obtained in the profile simulation.

This mathematical model will be called a water quality spatial simulation model, since it will attempt to reproduce spatially the maximum and minimum diurnal variations in water quality. The daily averages will subsequently be evaluated as the arithmetic average of the two extreme values. Equation 74 and its differential form will be used as the basis of developing the simulation model. Appropriate changes and conversions will be introduced to effect the improvements considered necessary to simulate the observed results obtained in the water quality studies. The greatest problem appears to be associated with modeling or simulating the effects of the algal environment on the observed dissolved oxygen relationships.

C. The General Form of the Mathematical Model

1. Basic concepts

The simulation model will first be integrated using the fundamental differential equation, assuming uniform flow and steady-state conditions. This provides the general form of the proposed mathematical model and permits additional comparison of the several terms which appear in the integrated form. However, to account for the additional complexities which were encountered in the stream environment (and listed in previous chapters), the differential form was used as the basis of the digital computer simulation model.

Diurnal application of the simulation model implies sufficient knowledge of variations in water quality parameters and rate coefficients to permit their evaluation. Algal photosynthesis will provide an oxygen contribution in the daytime whereas algal respiration will add to the dissolved oxygen deficit in the evening. Therefore, sequential application of the proposed mathematical model using daytime and nighttime conditions will provide boundary or profile extreme values, from which daily averages may be approximated.

The basic first-order reactions for assimilation of nonconservative pollutants will be used in this model as a simplifying but adequate mechanism. However, it is recognized that the actual assimilative processes may vary, as previously illustrated with the progression of biochemical oxygen demand. Before more advanced and complex assimilative models can be introduced into the modeling process, additional research is required for confirmation, and for obtaining laboratory and field estimates of the associated rate coefficients, ultimate values, etc.

2. Expressing the algal influence in mathematical terms

a. Selection of primary algal parameters The greatest inadequacy of Eq. 74 lies in expressing the effect of algae in the photosynthesis-respiration cycle. The term (P-R) is not constant, but increases from the background value existing upstream of the assimilative reach to a higher value as algal growth is nurtured by food and nutrients, and then reduces to the background value (or reasonably close to it) downstream of the assimilative reach. The nature of the day and night dissolved oxygen profile envelope curves, as shown in Figs. 59 and 62, suggests the introduction of a sinusoidal function for the observed increase in algal productivity. This effect is positive in the daytime, and negative at night, insofar as oxygen contributions are concerned.

Two parameters express the algal influence on the dissolved oxygen balance of the stream. These are the net rate of photosynthesis, (P-R), and the ratio P/R, of the gross rate of photosynthesis to the rate of respiration. In this study, these terms will be defined as

$$\overline{PMR} = P - R \qquad (126a)$$

and

$$\overline{PRR} = P/R \qquad (126b)$$

The nighttime respiration rate is evaluated as

$$\overline{R} = \overline{PMR}/(\overline{PRR} - 1) \qquad (126c)$$

where

P = gross photosynthesis rate of oxygen production and contribution, mg/l/hr,

R = respiration rate for nighttime application, mg/l/hr,

PMR = net rate of photosynthesis, mg/l/hr, or (P-R), and

PRR = ratio of photosynthesis rate to respiration rate, or P/R.

The results of the water quality field studies indicated that much higher DO levels are experienced in the assimilative reach than upstream of the outfall, which confirms that the PMR values also have a greater value. These increases can be expressed in terms of the selected parameters, PMR and PRR. As the magnitude of PMR increases, then additional oxygen contributions are obtained from the implied increased algal productivity. The relative change in the magnitude of the rate of respiration, R, depends upon the rate of increase of both PMR and PRR, as indicated by Eq. 126c. Appreciable increases in R, as PMR values are increased, reflect more constant PRR values in the assimilative reach. A small or no increase in the value of R reflects an increasing trend in PRR counterbalancing the increase in PMR.

b. Introduction of the sinusoidal spatial function   As stated previously, the nature of the DO profile curves, as shown in Figs. 59 and 62 suggested that a spatial sinusoidal function might be introduced to account for the increased rate of photosynthesis observed in the stream. The sinusoidal function permits a smooth transition from the background value of PMR to a maximum in the middle of the assimilative reach (neglecting lag effects for the moment). From the peak contribution, the rate declines to the background value existing upstream of the assimilative reach. This method offers a reasonable approximation of modeling the algal influence in a spatial environment. The maximum amplitude can then be expressed in terms of the background PMR value and also to the concentration of nutrients and/or food introduced at the outfall of the water pollution control plant.

The nighttime respiration rate (P-R = - R for P = 0) varies spatially in this concept as a form of a mirror reflection of the daytime positive sinusoidal function, for PMR. The magnitude of the amplitude may vary, however, and careful application of Eqs. 126a through 126c may be needed to simulate the observed response of the stream.

The spatial variation in PMR (and reflected nighttime R values) will be similar to the diurnal trace illustrated previously in Fig. 2. This trace illustrates the type of spatial sinusoidal function that is needed to produce the desired results, if the abscissa is expressed in distance. The rate of oxygen production by the algal environment can be expressed as a sinusoidal function (for the spatial consideration using the related temporal variation for steady-state conditions, $x = Ut$) using

$$\frac{dO}{dt} = (PMR)_a [1 + \frac{\sigma}{2} (1 - \cos \frac{\pi t}{\tau})]; \quad 0 < t < 2\tau \tag{127}$$

where

O = dissolved oxygen contributed to the water by algae in the daytime through the photosynthesis process, or required at night in the respiration phase, in mg/l,

$(PMR)_a$ = background or clean stream value of the net rate of photosynthesis, P-R, mg/l/hr,

$(PMR)_{max} = (1 + \sigma)(PMR)_a$ at $t = \tau$, the maximum net photosynthesis value in the assimilative reach, mg/l/hr,

$(1 + \sigma)$ = multiplication ratio representing the increase in PMR to a maximum value of $(PMR)_{max}$ in the assimilative reach, and related to the food level and nutrient concentrations in the effluent and stream,

τ = time of travel to the point at which $(PMR)_{max}$ occurs in the assimilative reach, or half the period of the sinusoidal function, in units of time (hours or days with proper constants introduced), and

t = elapsed time of travel, in time units of τ and with proper constants used to conform to hourly production of PMR.

Equation 127 applies to the period in which the time of travel of effluents is within the assimilative reach, for $t = 0$ to $t = 2\tau$. The relative rate of increase of $(PMR)_a$ to the maximum value $(PMR)_{max}$ is evident if $t = 0$, $t = \tau$, and $t = 2\tau$ are introduced successively in Eq. 127b. At $t = 0$, $dO/dt = (PMR)_a$, which represents the background algal contribution upstream of the outfall in the so-called clean stream reach. At $t = \tau$, the maximum value $(PMR)_{max}$, occurs and at $t = 2\tau$ the photosynthetic rate declines to the background value, $(PMR)_a$.

Equation 127 applies only to the assimilative reach, of temporal length 2τ. The background value of net photosynthesis, $(PMR)_a$, is used in reaches farther downstream. Although a Fourier series could be introduced to model the desired effect for a long spatial reach of the stream, it appeared simpler in this study to introduce Eq. 123 only when needed, and neglecting it thereafter. This is relatively simple to accomplish in a digital computer program with iterative techniques.

c. Evaluation of algal growth multiplication factors and time constant The parameter σ will be influenced by the effluent nutrient levels discharged to the stream; as such it represents an algal growth factor or multiplication factor. As indicated by Oswald and Gotaas (1957), the dry weight of algal cells produced, in mg/l, was found to increase with the concentration of BOD_5. The range of BOD_5 studied varied from 0 to 350 mg/l. The dry weight of cells produced increased almost linearly from 0 to 100 mg/l in the range of 0 to 50 mg/l of BOD_5, with decreasing rates thereafter. This increase in the dry weight of algae produced can be construed also as indicating an increased algal density and related oxygen production and oxygen contribution to the flowing water. More recently, Oswald and Golueke (1966) evaluated algal growth rates under various concentrations of phosphates (mg/l PO_4). The increased phosphate levels produced in general a logarithmic increase in algal growth, as discussed previously, for concentration up to 1 to 10 mg/l. Because the sewage BOD_5 used by Oswald and Gotaas in the first study was accompanied by up to 6 mg/l phosphorus (18 mg/l PO_4), then the increased algal growth obtained in the early study may also be attributed to the increase in phosphate and related nutrients. Although either variable, BOD_5 or phosphates, offers a reasonable means of expressing the relationship of algal growth and oxygen production with nutrient levels, the phosphates will be used in this study to reflect the more recent concern for nutrient loads discharged from water pollution control plants.

Two forms of suitable relationships are suggested which would permit the increased algal growth and oxygen production to be correlated to nutrient levels. These are, in terms of the parameters included in Eq. 127,

$$(1 + \sigma) = a(PO_4)^b \qquad (128a)$$

or

$$(1 + \sigma) = c + d[\log(PO_4)] \qquad (128b)$$

where

$(1 + \sigma)$ = multiplication ratio defined in Eq. 127,

PO_4 = concentration of orthophosphates (actually $PO_4^{\equiv}$) at the beginning of the assimilative reach after the effluent nutrient load is mixed in the stream, mg/l, and

a, b, c, and d are constants.

If concentrations of (PO_4) are essentially nonlimiting above a phosphate level of 1.0 mg/l or more, then Eq. 128a appears the more useful, with a low coefficient for b and with a value of a sufficiently high to produce the dissolved oxygen concentrations observed in the water quality field studies. Or a two segment curve using Eq. 128a could be introduced, breaking at the 1 mg/l PO_4 level. Although the studies of Churchill et al. (1962) indicated that respiration and P/R ratios were not appreciably influenced by temperature changes for an established algal environment, the rate of algal growth during the summer season and the algal relationships at very low river temperatures (approaching 32 deg F) may be affected by the observed temperature levels in Iowa streams.

These algal growth parameters will be analyzed further in the verification phase of the proposed digital computer mathematical model. The value of τ also can be evaluated in water quality simulation studies. It appears to be about 1/2 day for the Skunk River at Ames. This ex post facto technique appears to be the most feasible means of obtaining usable relationships in the absence of laboratory or other detailed research studies directed specifically toward their evaluation.

3. <u>The composite differential equation for the dissolved oxygen deficit</u>

Each steady-state differential equation (Eqs. 43, 62, 63, and 70) includes a few of the many factors influencing the dissolved oxygen resource of the stream. The primary factors contained in the mathematical model developed herein include the factors accounted for in the above equations together with the added influence of the algal environment as expressed in Eq. 127. The composite differential equation for the DO deficit then becomes

$$\frac{dD}{dt} = - rD \tag{129a}$$

$$+ \alpha k L_a \exp(- kt) \tag{129b}$$

$$+ \alpha k B[1 - \exp(- kt)] \tag{129c}$$

$$+ \beta n(4.57\ N_a) \exp(- nt) \tag{129d}$$

$$- A[1 + \frac{\sigma}{2}(1 - \cos \omega t)] \tag{129e}$$

where

D = dissolved oxygen deficit in the flowing water, mg/l,

r = reaeration coefficient, base e, per day,

k = deoxygenation coefficient for carbonaceous organic material, base e, per day, and is considered the river k value,

n = nitrification coefficient for nitrogenous organic material including ammonia, base e, mg/l,

L_a = carbonaceous organic waste oxygen demand, BOD_u, at $t = 0$, mg/l,

$B = \frac{p(24\ U)dt}{1 - \exp(-\ k\ dt)}$, the uniform contribution to the stream from its air-land boundary or interface, of carbonaceous organic material, mg/l, where

p = BOD_u boundary contribution in mg/l/mile,

U = average stream velocity, mph,

dt = time increment of a day used in iterative procedures,

α = the oxygen utilization ratio for carbonaceous material, a general expression for the K_1/K_r ratio of Thomas (Eq. 72),

β = the oxygen utilization ratio for nitrogenous organic material, as evaluated in this study (Eq. 117),

N_a = nitrogenous organic material in terms of ammonia (and possibly the organic nitrogen in the bacterial mass of the effluent discharge), measured in the stream at $t = 0$, mg/l N-nitrogen,

$A = (P - R)_a\ (24) = PMR_a\ (24)$, the "clean water" value or net photosynthesis attributed to the algal environment, mg/l/day, with A being positive in the daytime and negative at night,

$(1 + \sigma)$ = multiplication ratio representing the increase of A (or PMR_a) to the maximum amplitude of PMR_{max} in the assimilative reach, and

$\omega = \pi/\tau$, where τ is the time of travel to the point at which the maximum (or nighttime minimum) value of A occurs, per day.

The composite differential equation expressed in Eq. 129, including the revised algal term, remains a linear differential equation of the first order (Wylie, 1960) with constant coefficients. It is integrated as illustrated in Vol. I of this study, with additional evaluation required for the algal term of Eq. 129e. Additional evaluation is necessary also for the special conditions r = k and n = k. For steady-state conditions, the initial condition $D = D_a$ at t = 0 is sufficient to evaluate the constant of integration.

Step by step integration of Eq. 129 will not be included because of the relatively simple but tedious procedures involved. The complementary solution, D_{cs}, of Eq. 129 remains

$$D_{cs} = c_1 \exp(-\ rt)$$

for $r \neq k \neq n$. Both cos ωt and sin ωt functions must be included in the construction of the particular solution, D_{ps}. These can also be combined into one cosine term using a phase angle relationship.

The integrated form of Eq. 129, containing five terms (when $r \neq k \neq n$) is then obtained.

The mathematical model for the dissolved oxygen deficit contains five terms relating consecutively to the initial DO deficit, the oxygen demand of the carbonaceous effluent BOD_u loading in the stream, the boundary or bank load oxygen demand, the nitrogenous oxygen demand and the net oxygen contribution to the flowing water by the algal environment. The dissolved oxygen deficit resulting from all contributions and demands is:

$$D = D_a \exp(-rt) \quad (130a)$$

$$+ \frac{\alpha k}{r-k} L_a[\exp(-kt) - \exp(-rt)] \quad (130b)$$

$$+ \frac{\alpha k}{r} B[1 - \exp(-rt)] - \frac{\alpha k}{r-k} B[\exp(-kt) - \exp(-rt)] \quad (130c)$$

$$+ \frac{\beta n}{r-n} (4.57\, N_a)[\exp(-nt) - \exp(-rt)] \quad (130d)$$

$$\left. \begin{aligned} &- \frac{A}{r}\left(1 + \frac{\sigma}{2}\right)[1 - \exp(-rt)] \\ &+ \frac{\sigma A}{2}\left(\frac{r}{r^2 + \omega^2}\right)[\exp(-rt)] \\ &+ \frac{\sigma A}{2\sqrt{r^2 + \omega^2}} \cos(\omega t - \phi) \end{aligned} \right\} \quad (130e)$$

where

D = DO deficit, mg/1,

D_a = DO deficit at time $t = 0$, mg/1,

r = reaeration coefficient, base e, per day,

k = deoxygenation coefficient for carbonaceous material, base e, per day,

n = nitrification coefficient for ammonia in effluent, base e, per day,

L_a = carbonaceous organic waste demand (BOD) at t = 0, mg/l,

$B = \frac{p(24\ U)dt}{[1 - \exp(-\ k\ dt)]}$, the uniform contribution to the stream, from its air-land boundary, of carbonaceous organic material, in mg/l, and

p = BOD boundary contribution in mg/l per mile,

U = average stream velocity, mph,

dt = time increment (part of a day) used in iterative procedures,

α, β = carbonaceous and nitrogenous oxygen utilization ratios,

N_a = concentration of ammonia (including organic nitrogen) in the stream from the effluent source at t = 0, mg/l N-nitrogen,

$A = PMR\ (24) = (P - R)_a\ (24)$, the "clean water" value of net photosynthesis contributed to the flowing water by the algal environment, mg/l/day, with A being positive in the daytime and negative at night,

$(1 + \sigma)$ = multiplication ratio representing the increase of A (or PMR_a) to the maximum amplitude of PMR_{max} in the assimilative reach,

$\omega = \pi/\tau$, the angular velocity of the algal growth, per day, and where τ is the time of travel in days to the point of maximum amplitude,

= arctan (ω/r), the phase angle of the trigonometric function.

In the computer program developed from this basic mathematical model,

$$D = TERM1 + TERM2 + TERM3 + TERM4 + TERM5$$

where the terms TERM1, TERM2, TERM3, TERM4 and TERM5 pertain to Eqs. 130a, 130b, 130c, 130d, and 130e, respectively. The combined response indicated by the equations in this mathematical model is too complex to permit determining the critical values of time, t_c, and of the DO deficit, D_c, as expressed in Eqs. 47 through 58. A laborious trial and error solution is required unless iterative techniques are introduced through digital computer programming.

For the conditions r = k and/or r = n, the terms in Eqs. 130b, 130c and 130d must be replaced by the following terms:

$$TERM2 = \alpha k L_a t \exp(-kt) \quad ; r = k \qquad (130b\text{-}1)$$

$$TERM3 = \alpha k B t \exp(-kt) + \alpha B[1 - \exp(-kt)]; r = k \qquad (130c\text{-}1)$$

$$TERM4 = \beta n(4.57 N_a) t \exp(-nt) \quad ; r = n \qquad (130d\text{-}1)$$

The dissolved oxygen deficit can be determined for spatial steady-state conditions (temperature, discharge, and potential pollutant concentrations and contributions) using this mathematical model. The dissolved oxygen spatial profile can be obtained using Eq. 60, ($C = C_s - D$), which provides the actual dissolved oxygen concentrations, and incorporates also the spatial-temporal relationship, $x = Ut$, for the average time of travel.

4. Corollary mathematical models for nonconservative pollutants

The assimilation of organic materials or pollutants through the biochemical oxidation process, absorption or adsorption, dilution, or other forms of decay can be combined into an overall extraction phenomena. This extraction is implied in the mathematical model for the dissolved oxygen deficit, Eq. 130. However, the oxygen utilization ratios or factors (α, β) do not appear in the overall river extraction models for the selected pollutants that are included in the DO model. The following equations then become a part of the general water quality simulation model:

$$\text{BOD-CBN} = L = L_a \exp(-kt) \tag{131}$$

$$\text{BOD-NITR} = N = (4.57\, N_a) \exp(-nt) \tag{132}$$

$$\text{BOD-BKL} = B[1 - \exp(-kt)]$$

$$= \frac{p(24\, U)dt}{1 - \exp(-k\, dt)} [1 - \exp(-kt)] \tag{133}$$

where

BOD-CBN = concentration of carbonaceous BOD at any time t, mg/l,

BOD-NITR = concentration of nitrogenous BOD at any time t, mg/l, and

BOD-BKL = concentration of boundary BOD additions at any time t, mg/l, and

the other terms were defined in Eq. 130.

These are the primary water quality parameters or potential pollutants associated with the dissolved oxygen resource. Ammonia levels in the stream are given by the terms in Eq. 132 if the conversion factor

4.57 is neglected or omitted. Exponential decay of the coliform population can be included in a form similar to Eq. 131, although a growth or increasing trend should be permitted if the settleable solids (or raw sewage) are an appreciable part of the effluent discharge. The extraction of nitrates can follow the form of Eq. 131 but the added conversion of ammonia to nitrates must be included. In the mathematical model concepts used in this study, the low level of nitrites (or the inability to measure low levels of nitrites in the stream environment) indicated that both forms could be included in the nitrate category with little error. The concentration of phosphates, the remaining nutrient source, can also be expressed in the form of Eq. 131, with the associated rate coefficient identified specifically for this nutrient.

In the steady-state form, conservative substances do not need to be included unless extraction is observed through the adsorption-absorption process. For instance, the level of chlorides and silica in the stream did not change appreciably at the levels measured and are not included in the model.

5. Summary remarks concerning the general mathematical model

The general form of the mathematical model for simulating the response of the stream environment to effluents discharged to it indicates the several factors which influence the resulting stream behavior. The model is much more complex than the original formulation by Streeter and Phelps (1925). Perhaps in large streams the influence of effluents is minor compared to the background levels of water quality. In the current study, where effluents contribute significantly to the discharge of the stream, increased emphasis must be given to the reactions which have been observed. The result is the detailed model given as Eq. 130 with the additional reactions included as Eqs. 131 through 133. Use of the model to forecast stream response to a pollutional load under both day and night conditions provides both a spatial and temporal picture of water quality in a stream. Simple arithmetic average of the day and night boundary conditions (maximum and minimum) yields a first approximation to daily averages.

As expressed in Eqs. 130 through 133, use of the model is limited to steady-state spatial conditions. This includes constancy of discharge and of temperature after mixing at the outfall point, etc. This severely limits the use of the model in most stream environments, including the Skunk River. It does provide a means of comparing results with other forms or models of the dissolved oxygen deficit, and related water quality parameters.

Because of the spatial variations observed in the Skunk River water quality studies that may have a considerable impact on simulation or forecasting, the differential form of the mathematical model as expressed in Eq. 129 was used as the basis of a digital computer model. This permits introducing spatial variations in discharge and temperature, simplifies the use of iterative methods, and avoids the complications introduced if $r = k$ or $r = n$, or both. The development and application of the digital computer model using the basic equations presented in this section are described in the following sections of this chapter.

D. The ISU Water Quality Model

1. General requirements

A digital computer water quality simulation model was developed for spatially describing the diurnal response of the stream environment to the discharge of municipal effluent. The computer model was developed from the mathematical model of Eq. 129 for the differential equation of dissolved oxygen deficit and the differential equation form of Eqs. 131 through 133. The quantitative relationships developed (in the previous chapter) through the analysis of the water quality stream data were also incorporated into the digital computer simulation model. The differential form of the response equations permits including spatial variations in observed hydrologic and water quality factors, and can be adapted easily to iterative computer techniques. The water quality parameters that will be included in the simulation model will be outlined first. The segments which make up the model will be discussed next. The various input data required for making a simulation study will then be discussed. Application and verification of the simulation model will then be explained.

2. Water quality parameters included in the simulation model

The water quality parameters associated with stream standards are of major importance in considering a simulation model of the Skunk River. These include not only those parameters associated with the biodegradable organic wastes and the dissolved oxygen resource, but also those related to other potential pollutant problems. These include heat and temperature effects, coliform die-away, and ammonia toxicity. The latter is of a serious nature in view of the low ammonia levels permitted in the Iowa standards (limited to 2 mg/l or less) and of the large quantities and concentrations contained in effluents from water pollution control plants.

Evaluation of the following water quality parameters and/or potential pollutants was included in the simulation model:

(1) Time of travel and related distance downstream from the initial point of reference, to describe the spatial location of occurrence of water quality levels in the stream.

(2) Spatial description of the river temperature, for both daytime and nighttime conditions and the arithmetic average of the two.

(3) The spatial description of the total stream discharge, permitting incremental changes in conformance to observed or predicted discharges.

(4) Concentrations of dissolved oxygen, with algal photosynthesis providing an oxygen contribution in the daytime, but becoming a respiration liability at night. The arithmetic average of the two is reported as an approximation of the mean daily DO levels in the stream.

(5) The mean daily concentration of ammonia, to reflect its magnitude in comparison with the limiting stream standard of 2 mg/l, and its related toxicity to stream biota.

(6) The mean daily level of BOD in the stream, with either ultimate values or simulated 5-day values provided as output. The several forms of BOD that are included are:

(a) Effluent BOD contribution to the stream at the outfall point and its assimilation or extraction in the downstream direction.

(b) The boundary or bank load of BOD that is contributed along the length of the stream.

(c) The sum of (a) and (b) which, with the initial BOD of the stream, represents the carbonaceous BOD levels in the stream.

(d) The nitrogenous BOD level, as contributed by the effluent and subsequent additions in the downstream direction.

(e) The total BOD level in the stream, consisting of the carbonaceous and nitrogenous BOD demands.

(7) The mean daily concentration of nitrate in the stream, reflecting the nitrite-nitrate combination in this model.

(8) The mean daily concentration of phosphates, which serves as an indicator of the response of the assimilative reach to nutrient loads and also of the return to "clean stream" conditions.

(9) The relative levels (mean daily) of fecal coliforms remaining in the stream from effluent discharge at the outfall point.

The number of parameters of water quality that could be included in the model and evaluated in the study was limited because of the time and effort available, or because of lack of knowledge of the specific response of the stream. Although specific data concerning coliform levels in the Skunk River water were not obtained, sufficient information was available from the State Health Department field studies at Ellsworth on the Skunk River and at other locations in Iowa to formulate a first approximation of the relative rates of decrease or removal of coliform bacteria (representing fecal coliform levels).

By spatially describing the water quality parameters under daytime, nighttime, and mean daily conditions, a rather complete description of water quality can be obtained. Simulation of the observed water quality levels for the period of study provided sufficient familiarity with the nature of the response of the stream that forecasting of water quality levels for future conditions was possible. This was the goal in the development of the digital computer simulation model.

3. Sequential elements of the ISU water quality model

a. Basic concepts The basic concept and elements of the spatial water quality simulation model are shown in Fig. 76. The input data establishes (1) the background level of stream water quality and (2) the discharge and pollutant levels of the effluent at the outfall point. Daytime analysis is initiated first, with algal photosynthesis and atmospheric reaeration counterbalancing the oxygen demand of biodegradable substances. Water quality levels at the outfall station following mixing establish the overall magnitude of the algal response in the assimilative reach, and the nature of the coliform decay relationship. The model then proceeds to analyze downstream effects of transport, assimilation, dilution, and overall extraction phenomena on the selected water quality parameters and pollutants. Dispersion effects, as in the basic Streeter-Phelps model modified by Thomas (1948), are included indirectly in the rate coefficients as determined in the river water quality studies, and are not evaluated directly.

Results of the daytime analysis are withheld in storage (in appropriate arrays) through a matrix system notation. Upon completion of the daytime analysis, the model cycles back to the initial outfall station and evaluates nighttime conditions, the results of which are also placed in storage. Upon completion of the determination of water quality levels in the stream under nighttime conditions the mean daily values are obtained by averaging the day and night results. Selected results are then printed out. The model includes a routine for plotting selected water quality parameters. Sequential cycling is an optional

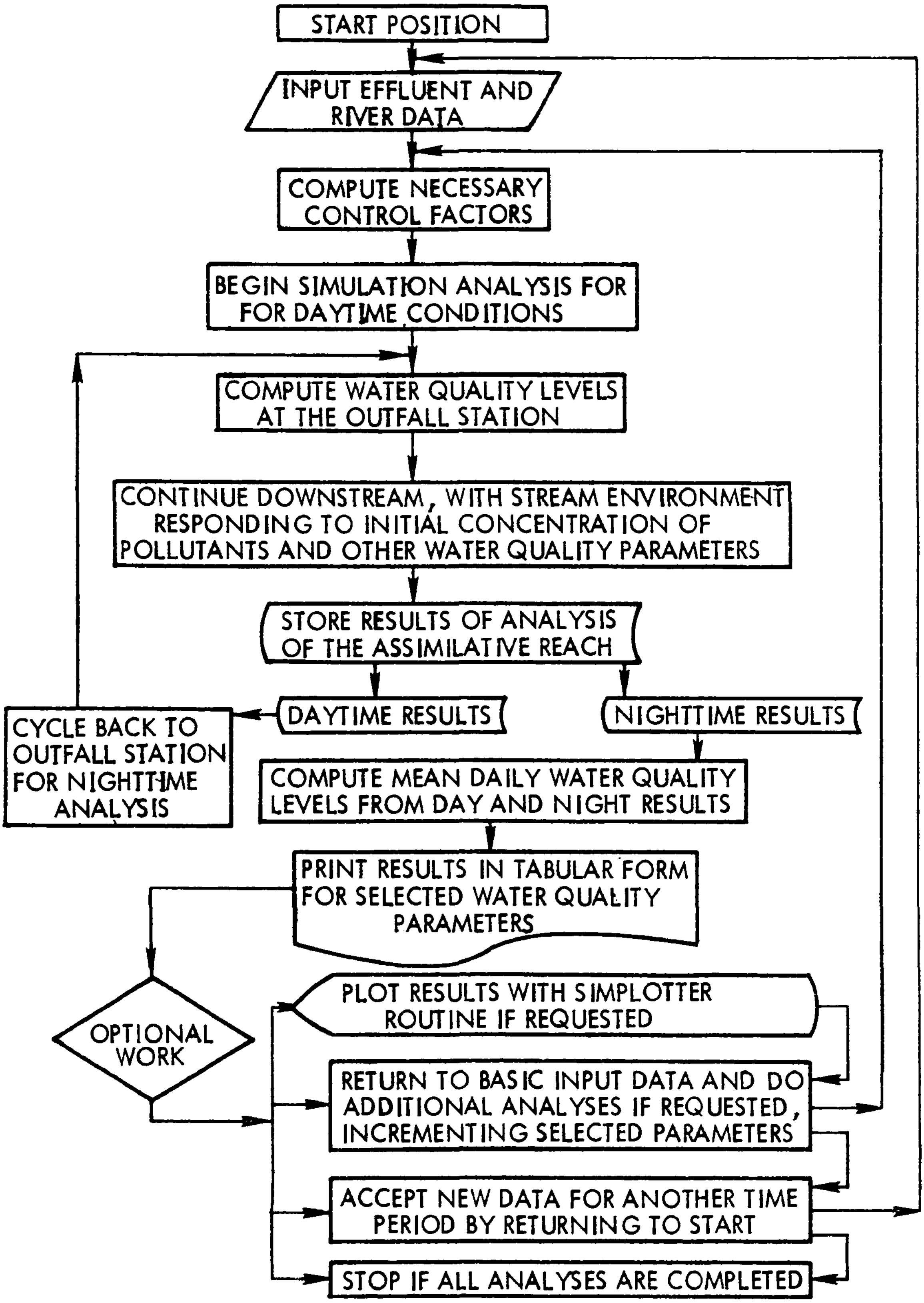

Fig. 76. Sequential elements of the Ames water quality simulation model.

feature of the model, permitting incremental changes in boundary BOD additions, algal effects, or low-flow augmentation to be made.

b. Additional development factors The program elements as described above indicate that comprehensive analysis of the response of the stream environment can be made using the ISU water quality model. Printout of the 14 water quality parameters listed in the previous section provides a spatial description of the day, night and/or mean daily water quality levels. Additional summary data are provided for beginning and end of assimilative reach values of the selected water quality parameters for both day and night analyses. Optional printout of intermediate data, including rate coefficients and other miscellaneous data, can be accomplished.

The program for the ISU water quality model was prepared for the IBM System/360 Model 65 digital computer operated by the Iowa State University Computation Center. It was written in FORTRAN IV language, and utilizes a substantial amount of internal storage. However, a complete analysis for the 9 study periods used in verification studies required less than 1 minute of computer execution time. One hundred spatial determinations were made in the assimilative reach for each study period, with three determinations at each spatial location (day, night, and daily mean) for each water quality parameter. Thus, 2,700 determinations, each requiring several sequential calculations, were made in the verification studies for the 14 selected water quality parameters.

The separate "building blocks" of the model will be described in the following sections. The simplified flow chart for the digital computer model is illustrated in Figs. 77a, b and c. A block by block discussion of the flow chart will be made to describe the program and its various functions. A complete listing of the source program is provided in Appendix E.

4. Block 1 of the model

The first block of the computer program (Fig. 77a) consists of the input control, initializing input and output arrays, transferring input data to the proper variable names, and converting rate coefficients from base 10 to base e. Then follows the determination of initial effluent and stream conditions, background water quality levels, river extraction rates for BOD, initial factors for algae growth and oxygen productivity, the coliform die-away relationship, and the base day and night temperature levels for the stream.

a. Basic input data and job cards Seven basic input job cards contain the effluent and river data required for evaluation of the response of the stream environment. The first card, No. 1, is used for identifying the stream or reach of stream being studied. The second card, No. 2, identifies the specific computer run being made, including date, type and degree of waste treatment, and any other desired information. This card also includes the season identification (month or one of the four seasons).

The next four cards, Nos. 3 through 6, contain space for numerical data for 15 designated parameters of water quality. Card No. 3 is designated EFFL in the array notation, and contains the effluent water quality data. Card No. 4 is designated as RWQD, and contains the river

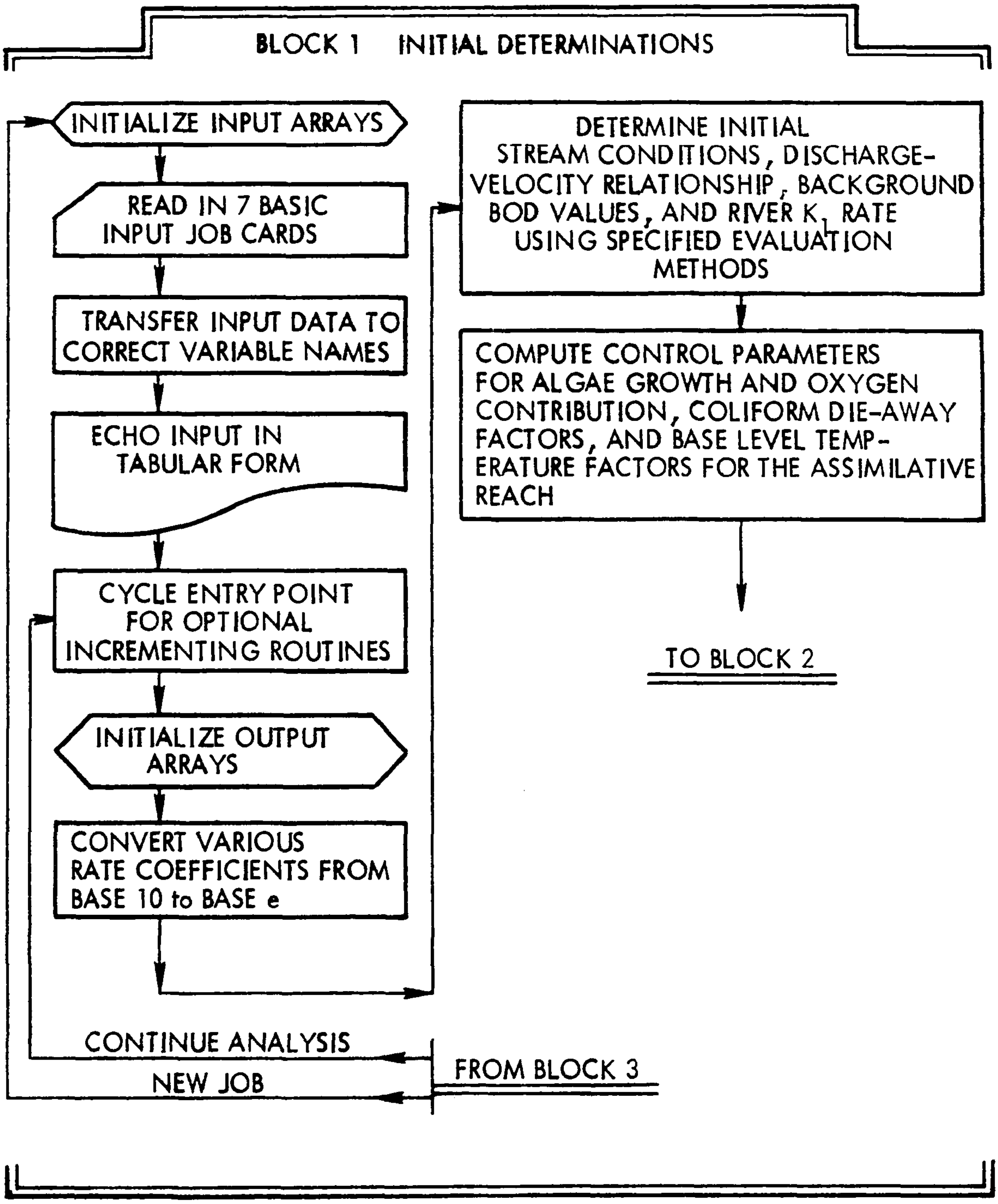

Fig. 77a. Simplified flow chart for the ISU water quality simulation model, block 1.

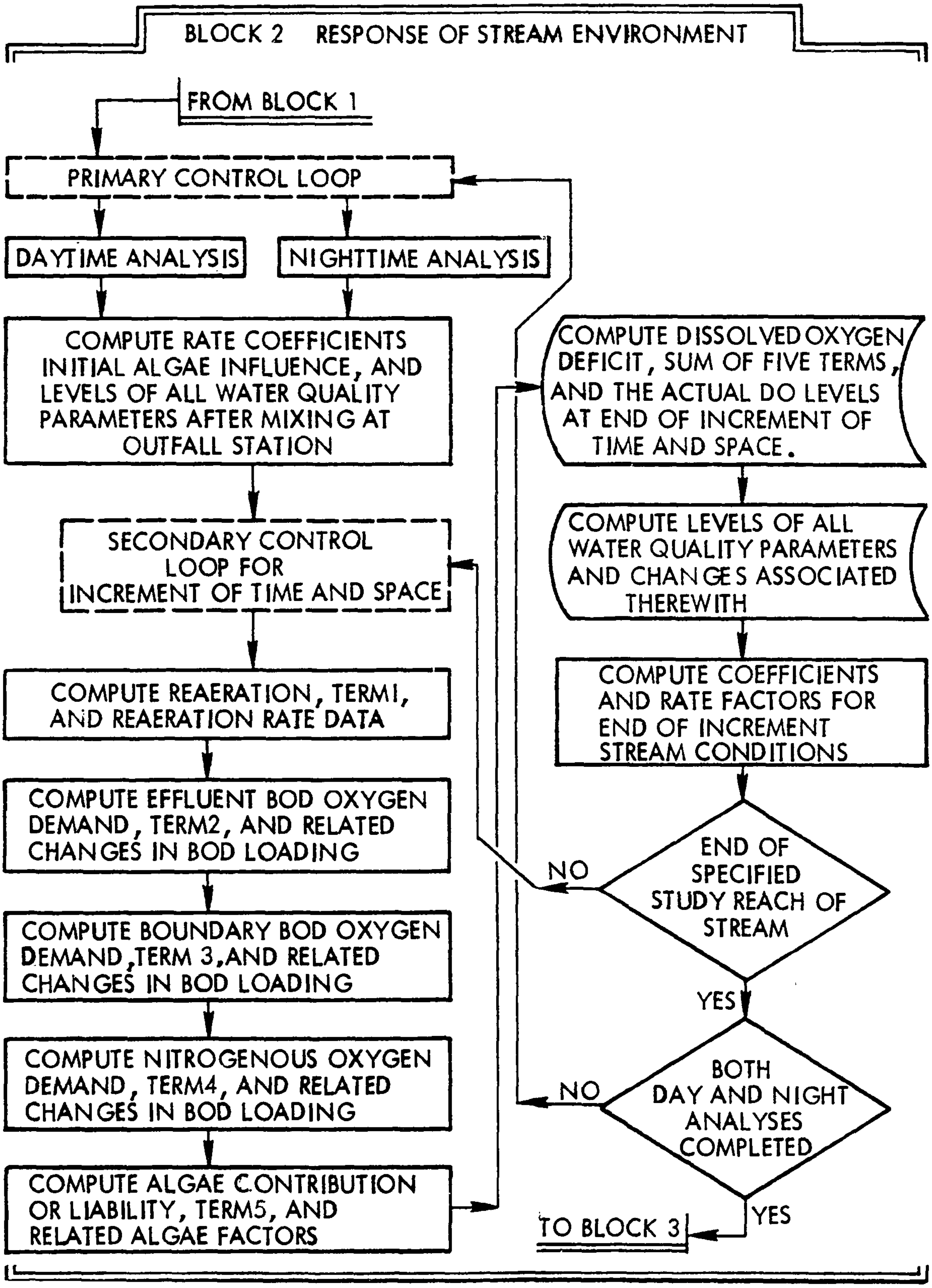

Fig. 77b. Simplified flow chart for the ISU water quality simulation model, block 2.

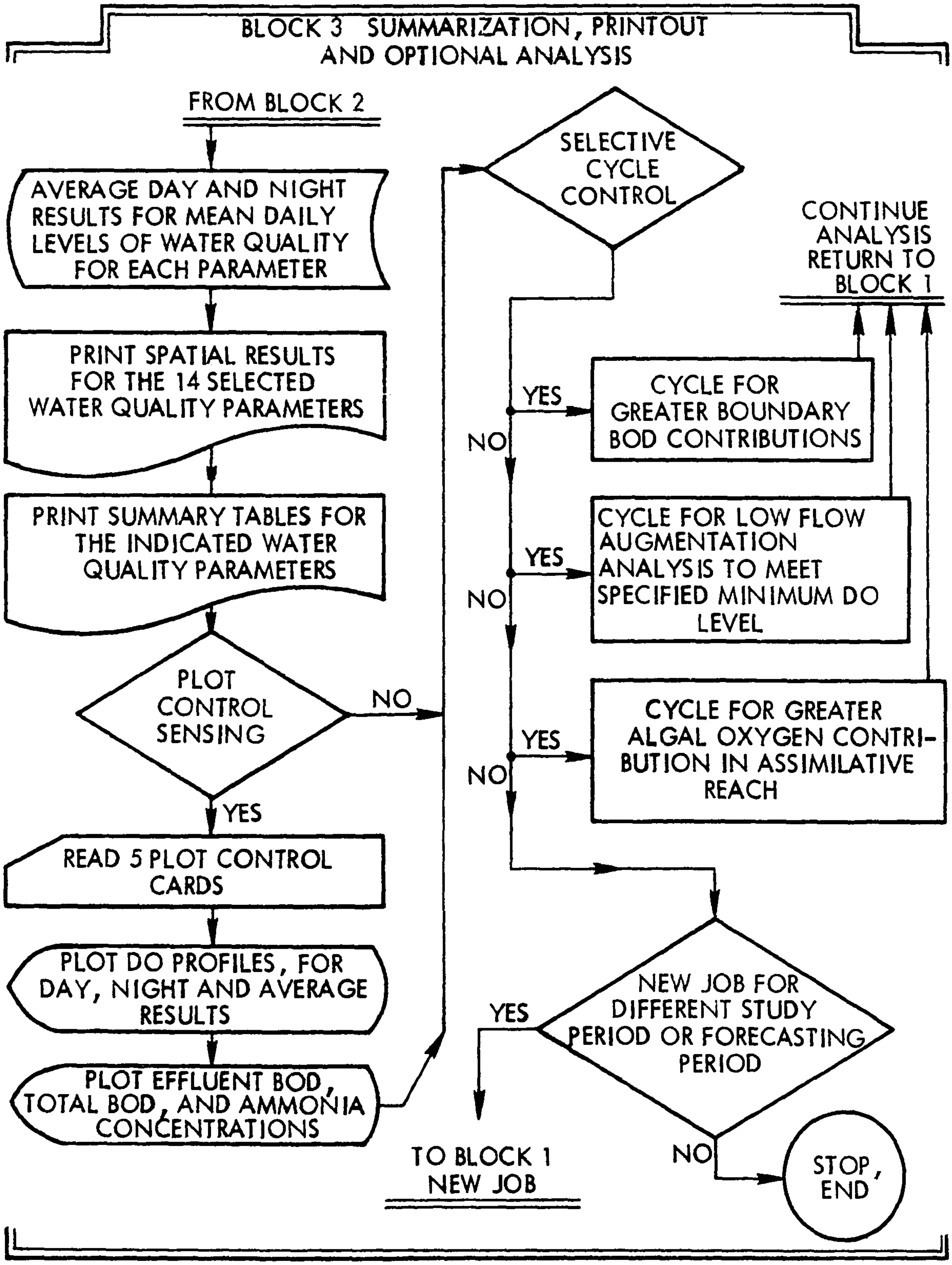

Fig. 77c. Simplified flow chart for the ISU water quality simulation model, block 3.

water quality data. Card No. 5 is labeled RQVD, and contains the river discharge and velocity information, several rate coefficients and other factors. Card No. 6 is labeled ALGTP and contains the algae control data and other miscellaneous rate coefficients. A total of 56 data values (of the 60 available array positions) are required for operation of the ISU water quality model, with a few being computed internally if not specifically provided. Data card No. 7 includes miscellaneous operation control parameters required for output control and for sequential incrementing of desired variables. Eleven items of control information are included on this job card.

An additional five cards (Nos. 8 through 12) are required if the plotting routines for dissolved oxygen, biochemical oxygen demand and ammonia are to be activated. Otherwise the additional cards are not required, and a control parameter in card No. 7 permits bypassing the plotting routine.

b. Description of all input data   The water quality parameters included in job cards 3 through 7 will be described in detail to familiarize the reader with the information required.

Effluent data, EFFL (card 3):

1. QEMGD   The average daily discharge of the water pollution control plant, in mgd.

2. TEMPE   The average daily temperature of the effluent as discharged at the outfall, deg F.

3. PCSE   The average daily percent DO saturation of the effluent, since it is an asset.

4. BODE   The carbonaceous BOD_5 of the effluent, mg/l.

5. KDE   The laboratory K_1 rate for the effluent BODE, per day.

6. LAE The ultimate BOD of the effluent, mg/l (computed internally if not provided in the input data).

7. AMNE The ammonia concentration in the effluent, mg/l-N.

8. NITRE The nitrate concentration (and nitrites, if desired) in the effluent, mg/l-N.

9. PO4E The orthophosphate concentration in the effluent, mg/l.

10. COLIE The relative level of fecal coliforms in the effluent, expressed as a percent of some reference value (a value of 100% was adopted for the case study to represent the plant outfall level as compared to stream background values).

11. GAMMA1 The factor γ_1 described previously in the water quality field studies, representing the proportion of the ultimate BOD of the stream (after mixing) that will be exerted in the 5-day BOD laboratory test.

12. GAMMA2 The factor γ_2 described also in the water quality studies, representing the proportion of the nitrogenous BOD that will be exerted in a 5-day laboratory test.

River water quality data, RWQD (card 4):

1. TMPRD The daytime maximum temperature of the river upstream of the outfall, deg F, as it might be influenced by extraneous other urban sources.

2. TMPRN The corresponding nighttime maximum temperature of the river immediately upstream of the outfall, deg F.

3. PCSRD The maximum daytime percent DO saturation in the stream that corresponds with TMPRD, and must be selected to represent the influence of algae and upstream waste load effects, etc.

4. PCSRN The corresponding minimum nighttime percent DO saturation in the stream DO, reflecting algal respiration, etc.

5. BODR The residual carbonaceous BOD loading in the river (upstream of the outfall), mg/l, reflecting upstream urban waste load residuals, and miscellaneous local urban sources such as storm sewers, etc.

6. KDRLB The laboratory K_1 value associated with BODR, per day.

7. LAR The corresponding ultimate BOD associated with BODR,(computed internally if not specifically provided).

8. AMNR The ammonia concentration of the stream upstream of the outfall, mg/l-N, used as the background value for the study reach.

9. NITRR The concentration of nitrates (and nitrites, if desired) in the stream at the outfall, and the background value.

10. PO4R The concentration of orthophosphates in the stream at the outfall, mg/l, used as a background value in the study reach.

11. COLIR The relative level of fecal coliforms in the stream above the outfall, expressed as a percentage in conformance to the relative value of COLIE, used also as a background value in the study reach.

12. BLX The boundary BOD_5 contribution to the stream at the outfall point, expressed as pounds per mile per day.

13. DBLX The per mile increase in BLX to reflect an increased boundary addition as the stream channel increases in size, additional tributaries enter, etc.

14. ALPHA the α factor of Eq. 130, representing the relative oxygen demand associated with the river carbonaceous BOD extraction rate, KDR.

15. BETA The β factor of Eq. 130, representing the relative oxygen demand associated with the nitrogenous BOD required for that portion of the nitrogenous BOD assimilated by nitrogenous bacteria.

River discharge-velocity data, RQVD (card 5):

1. QRCFS The discharge of the stream above the outfall, cfs.

2. DELQX The per mile linear increase in stream discharge, as observed or estimated, cfs/mi.

3. PSDQD The daytime percent DO saturation of the increase in discharge, which is low for groundwater contributions but higher if surface inflow is included in DELQX and influenced additionally by the algal environment.

4. PSDQN The corresponding nighttime DO saturation value, in percent, associated with DELQX.

5. CVA The coefficient for average stream velocity versus discharge, as expressed in Eq. 114.

6. CVB The exponent in Eq. 114, for average stream velocity.

7. XIN The initial mileage station, in miles, at the outfall of the pollution control plant at the beginning of the assimilative reach being studied.

8. TIMIN The initial time, in days, designated as the beginning of the study.

9. TIMFN The final time, in days, at which computations are to stop.

10. DTIM The increment of time, in days, for computation purposes, which must be sufficiently small for Eq. 129 to be used without introducing large errors.

11. KCOLI The river extraction rate for coliforms, per day, base 10.

12. KPOR The river extraction rate for orthophosphates, per day, base 10.

13. KNTR The river extraction rate for nitrates, per day, base 10.

14. KNR The river extraction rate for ammonia, per day, base 10.

15. KDR The river extraction rate for carbonaceous BOD, per day, base 10, computed internally using Eq. 116 if not specifically provided.

Stream algae and temperature control data, ALGTP (card 6):

1. TPBRD The maximum daily base level temperature of the stream, to which the temperature of the stream (after mixing at the outfall) will revert with time, deg F.

2. TPBRN The corresponding minimum daily base level temperature of the stream, for nighttime analysis, deg F.

3. KCTBR The rate coefficient for the decay of the temperature differential existing following mixing at the outfall, per day, base 10.

4. TMPAD The maximum daily air temperature, deg F, for the month or season being studied (weekly average or daily

maximum, etc.), from which TPBRD will be computed internally if not specifically provided (using discharge as the temperature differential determinant).

5. TMPAN The corresponding minimum daily air temperature, deg F, for nighttime analysis.

6. CAALG The algal coefficient to be used in Eq. 128a.

7. CBALG The algal exponent to be used in Eq. 128a.

8. TAUTM The value of τ to be used, in days, as observed or estimated, as defined in Eqs. 127 through 130.

9. PMR The base level of (P-R) for the stream reach being studied, mg/l/hr.

10. PRRIN The corresponding base level of PRR, or P/R, from which the nighttime respiration value, R, is obtained, Eq. 126.

11. PRRMX The maximum value of P/R that can occur in the assimilative reach downstream of the outfall, associated with PMR_{max}, which permits the increase in R to be varied or controlled in conformance with the maximum PMR value.

12. DOFSH The minimum DO level required for the aquatic habitat, mg/l, which is used in the low-flow augmentation iteration sequence.

13. K2ICE The reaeration coefficient to be used in winter periods, per day, base 10, to reflect ice cover limiting or eliminating the atmospheric reaeration of the stream.

14. K2R The coefficient of atmospheric reaeration, per day, base 10, computed internally using Eq. 121 if not specifically provided.

Miscellaneous output and cycling control parameters (card 7):

1. IBLCY The number of iterations to be completed for additional boundary load study as BLX is increased (with DBLX held constant).

2. DBLCY The increment of boundary BOD by which BLX is to be increased at the start of each repeat cycle, lb/mi/day.

3. IDQCY The number of iterations to be completed for the low-flow augmentation cycling option, unless DOFSH is reached first.

4. DLQCY The increase in stream discharge (reservoir release rate) by which QRCFS is to be increased, cfs, in the iterative sequence to meet the DO level as expressed in DOFSH.

5. ILGCY The number of iterations to be completed for additional algal studies.

6. DPMR The increment to be added to PMR at the start of each cycle, mg/l/hr.

7. IWTRA A winter control parameter for suppressing algal contributions in the winter season, an integer number:

a. 0 specifies continued use of the summer PMR and R values with no reduction or suppression, for open water.

b. 1 specifies a 50% suppression of PMR and R values, for thin ice cover and low temperatures.

c. 2 specifies an 80% suppression of PMR and R values, for thicker ice conditions and low water temperatures.

d. 3 specifies using respiration values for both day and night, for thick ice and/or heavy snow cover, but with respiration values suppressed as in condition 2.

8. IPNCH This control number activates a card output sequence if desired; 0 for bypassing, 1 for card output.

9. IWRIT This control number activates a printout of intermediate results permitting inspection of rate coefficients, etc., at every time increment in the computations for the assimilative reach; 0 for bypassing, 1 for printout.

10. IPLOT This control number activates the plotting routine, and requires insertion of card Nos. 8 through 12 for operation; 0 for bypassing, 1 for plotting.

11. NLIN This specifies the number of lines to be printed on each page of the computer output sheets, for the water quality determinations in the assimilative reach.

These parameters representing the input data were selected as the most essential, either on the basis of the water quality field studies or from initial trial and error results obtained with early versions of the ISU water quality model. Many changes and introduction of additional parameters were found necessary to obtain adequate simulation of the observed water quality levels in the Skunk River.

c. Continued operation of block 1 The input data in array form is transferred next to the proper variable names. All input data is first printed out in tabular form similar to the data input sheets, providing a check and a permanent record for each computer run. All output storage arrays are initialized as a final item in this preliminary phase.

All coefficients required in the program are converted next to base e from the base 10 input values. Unless included specifically in the input data, the river extraction value, KDR, is computed through an analysis of the effluent and river BOD sources. The reaeration coefficient, K2R, is evaluated in a similar manner, being computed from the discharge data unless specifically included in the input data. Initial stream velocity and time of travel relationships, the increment of additional discharge to be added for each time increment, and a summary of the background stream BOD sources are also computed in this phase. If requested (through zero values of TPBRD and TPBRN), the base level stream temperatures for day and night are computed using the maximum and minimum air temperatures (which must then be provided). The relationship obtained through analysis of the air and stream temperatures was

$$DIFTMP = 1.25\ (QRCFS)^{0.3} \qquad (134)$$

where

DIFTMP = difference between maximum air and maximum water temperatures, or between minimum water and minimum air temperatures, and

QRCFS = stream discharge above the outfall point.

Although seasonal influence is neglected in Eq. 134, it serves as an initial approximation for the observed differences between air and water temperatures. In those instances where only recorded air temperatures are available, it provides a means of estimating water temperatures.

Initial algae and coliform control parameters that are nutrient or temperature dependent (or both) are then computed. Using a form of Eq. 14, the increase in algal productivity with temperature was made only slightly temperature dependent by a low coefficient value of 1.01. The location of the point of maximum algal productivity where PMR_{max} occurs, τ, was found to be much more dependent on temperature than was the actual productivity levels. A coefficient of 1.07 was used in the final simulation runs, with an inverse relationship indicated. The value of τ increases for low temperatures, and decreases for higher temperatures. The coliform die-away factors were made temperature dependent, with a coefficient of 1.05 to reflect the usual bacterial assimilation coefficient of 1.047 in Eq. 14. The increase in algal productivity with increases in nutrient is accomplished in this phase using a two-limbed relationship for Eq. 128a. Algal productivity increases significantly up to a phosphate value of 1.0 mg/1, then a low value for the exponent in Eq. 128a limits the increase in algal productivity. Provision is also made for decreasing the computed algal productivity values for winter conditions (low temperatures and the effect of ice and snow cover).

5. Block 2

The computations that represent the response of the stream environment to effluent discharge are included in block 2 (Fig. 77b). Daytime analysis is initiated and completed first, followed by the nighttime analysis.

a. Computation of water quality levels after mixing Initial water quality levels of the mixture of stream and effluent are computed first, using Eq. 1. Rate coefficients, being temperature dependent, are evaluated next. The rate of nitrogenous BOD uptake is reduced at DO levels less than 2 mg/l, and completely eliminated at levels less than 0.5 mg/l. To reflect slower reactions for the other coefficients under very low DO conditions (less than 0.5 mg/l), up to a 25% reduction is permitted as the DO level is reduced to zero. Additional evaluation of initial algae oxygen productivity is also made in this first phase.

b. Sequential analysis in the downstream direction Computations of water quality levels in the downstream direction are included in the second phase of block 2. A secondary control loop permits computing successive time increments of analysis. The five terms contributing to the total DO deficit (Eq. 130) are computed and the related water quality levels evaluated. The differential equation for the dissolved oxygen deficit (Eq. 129) is used in this part of the program. The combined effect of the five terms constitutes the change in the deficit for the time and related spatial increment being evaluated. The related DO level is then computed. A final check on both is made, to prevent a negative DO value from occurring, or a deficit value greater than the saturation value.

The levels of all other water quality parameters are computed in the third phase. The amount of ammonia converted to nitrates is added to the nitrate levels, which themselves are involved in the decay or extraction process. The coliform model permits an increase (by a factor of 4) in coliform levels for the first 12 hr of travel time if raw sewage (BOD_5 greater than 150 mg/l for BODE) or heavily polluted organic wastes are discharged to the stream. Thereafter, the decay concept is reapplied, decay taking place from the higher coliform level.

The final phase of block 2 consists of computing new rate coefficients and the extraction of utilization factors used in the next increment of time and space analysis. A check is then made for completion of computations for the assimilative reach, as specified by the time period (TIMFN-TIMIN), and for the daytime period. An intermediate printout is available at this point for obtaining a detailed record of the rate coefficients, the oxygen deficit values as represented by each of the five terms in Eq. 130, and other factors at each step of the assimilative reach computations. The computer sequence then causes the computations to return to the primary control loop position for initiation of the nighttime analysis. Once both day and night analyses are completed for the specified study reach, control passes to block 3.

6. Block 3

This block (Fig. 77a) consists primarily of the output control phase for tabulating all results, and optional routines used in conducting additional analyses.

a. Tabulation and plotting routines Average daily values for each of the selected water quality parameters are obtained as the arithmetic mean of the daytime and nighttime results at each time increment. The results of the analysis are then printed out in three tables. The first table includes the spatial description of (1) the time increment, (2) the related stream location in terms of miles downstream from the initial starting station, (3) day, night and average daily river temperatures, (4) river discharge, (5) day, night, and average dissolved oxygen levels, and (6) the average daily ammonia concentration. The second table includes the first two items above, (1) the time increment, and (2) the related distance downstream, and the following additional average daily values: (3) effluent BOD values, (4) boundary BOD values, (5) total carbonaceous BOD values (items 3 plus 4), (6) nitrogenous BOD values, (7) the total carbonaceous and nitrogenous BOD values (items 3, 4 and 6), (8) the level of nitrates, (9) the level of phosphates, and (10) the coliform index values, as percent remaining of the original reference value. Simulated 5-day BOD values are computed, printed and plotted if GAMMA1 and GAMMA2 are less than 1, permitting more realistic and comparative results with observed BOD field observations.

Table 3 is a data summary table for the reach. Day and night values for each of the above listed water quality parameters are tabulated for the initial station following mixing (at the outfall station), and for the end of the assimilation reach (designated as 2 x TAUTM). The minimum dissolved oxygen values for both day and night are retained during the computer analysis and also are included in the summary table. The time increment and spatial location of each value are also tabulated (this 3-table method of presenting results appears to be the most advantageous if complete listing of the voluminous amount of day, night, and mean daily results is to be avoided).

A plotter routine provides two plots for each study or forecasting period. In the first, the dissolved oxygen results are plotted for day, night and mean daily values with miles downstream as the spatial parameter. In the second, the total (carbonaceous and nitrogenous) BOD, the effluent BOD, and the ammonia concentration are plotted against the same spatial parameter. Because of the computer time and expense involved, the remaining water quality parameters were not included in the plotting routine. However, additional parameter plots can be added, if desired, in the future.

Five additional input cards are required if the plotting routine is exercised through the IPLOT control in card No. 7. These are described as follows:

Card 8: 1. Abscissa label for dissolved oxygen plot (miles downstream).
2. Ordinate label for dissolved oxygen plot (DO level, mg/l).
3. General label for the DO plot, indicating date of run or other data for identification purposes.
4. Specific label for daytime DO levels (daytime results).

Card 9: 1. Specific label for mean daily DO levels (average of day and night).

2. Specific label for nighttime DO levels (nighttime results).

Card 10: 1. Abscissa label for BOD and ammonia levels (miles downstream).
2. Ordinate label for BOD and ammonia levels (BOD and NH4, mg/1).
3. General label for the plot, indicating date of run or other data for identification purposes.
4. Specific label for the total BOD levels (total BOD, CBN-BOD, AMN).

Card 11: 1. Specific label for the effluent BOD levels (effluent BOD level).
2. Specific label for the ammonia levels (ammonia level).

Card 12: 1. The abscissa scale factor, XSF, for equating total reach length with the 8-in. specified size of the plot for DO, BOD and NH4.
2. The ordinate scale factor, YSF, for equating the maximum DO value with the 5-in. specified size of the plot for DO.
3. The ordinate scale factor, ZSF, for equating the maximum BOD or NH4 value with the 5-in. specified size of the plot for BOD and NH4.

b. Selective cycle control for additional analyses A selective cycle control, following the plotter routine, is then encountered in the operation of the computer model. This control system permits additional analyses for (1) boundary BOD contributions through increases in the parameter BLX, (2) low-flow augmentation (additions to QRCFS) from reservoir or groundwater storage to meet the minimum DO level specified as DOFSH, and/or (3) increased algal oxygen contributions or productivity through increased levels of the parameter PMR. Desired routines are activated by preselected and designated control values listed in card 7 (careful use of these additional routines is suggested; otherwise, a voluminous amount of output is obtained; no more than 5 cycles for each of the three additional analyses listed above are recommended). Following each additional analysis, the original value of the specified parameter changed in the reruns is returned to the system (the input value of BLX, QRCFS, and PMR).

The selective cycle control was used in the verification phase of the water quality studies where it was necessary to determine the magnitude of the influence of certain water quality parameters about which little was known. It was of less value when the program was used to forecast present or future conditions.

The final control element at the end of the operating portion of the computer program either stops the program or returns to the start position for a new job. This permits stacking several jobs for various study periods. The remainder of the program listing included in the nonoperational phase of block 3 is assigned to the format listings for both input and output. This avoids cluttering the main program source listing with the extensive format descriptions required for tabulating the results.

7. Subroutines

Two mathematical function subroutines are included in the ISU water quality model. The first function, AKRQ, computes (upon request) the reaeration coefficient K2R using Eq. 121a or 121b. This subroutine is included since it is needed at various points in the computational process.

The second function, DOS, is used to compute the saturation value of dissolved oxygen for any specified stream temperature using Eq. 32. A reduction of 3% in the dissolved oxygen at saturation is applied to correct for the average elevation of the study stream. Additional refinement was not introduced into the present version of the water quality model because of the many variables which were encountered in the course of the field studies. The additional effect of dissolved solids or of heavily polluted water on the saturation content could be introduced later if desired. However, for stream studies in which secondary treatment and/or additional tertiary treatment predominates, the additional refinement would not appreciably change the saturation value of dissolved oxygen.

8. Proposed operation manual

An operation manual is being prepared to describe the use of the ISU water quality model. This will permit more detailed explanation of the various terms and computational procedures contained in the mathematical model. The source listing in Appendix E provides the basic information required for review and use by experienced computer programmers. Sufficient headings are provided in the source listing to explain the digital computer computational procedures used.

Initial development efforts were directed to development of a simple, general program that could be applied to any reach of stream in which point effluent sources were located. However, this technique had to be modified to fit the scope and purpose of the case study of the Skunk River. Therefore, the ISU water quality simulation model is a general program to a limited degree, but containing certain mathematical expressions developed and included for specific use in the Skunk River case study.

E. Verification Studies Using Observed Data

1. General

The data collected during the 1966-67 water quality study of the Skunk River downstream of Ames were used to verify the proposed water quality model. Nine observation periods were used for this purpose. One additional dissolved oxygen profile was obtained during the winter of 1968-69 as part of a new research program studying groundwater and surface water relationships in the Skunk River basin (Sendlein and Dougal, 1968). This additional information was introduced to illustrate the difficulties of simulating winter conditions and to confirm the existence of low reaeration coefficients in winter periods under thick ice cover.

The nine observation periods will be described in the first section. Techniques of analysis and development procedures used will be outlined in the second section. The final results for the nine observation periods will be summarized in the third section. Additional analysis of winter conditions will be reported in the fourth section, followed by a final discussion and summary of the model verification studies.

2. Description of the nine observation periods

The nine observation periods represent the sequential development annually of the algal environment of the stream ecological habitats. These included summer, fall, and winter periods following early summer floods that have been a common occurrence in recent years in the Skunk River basin (U.S. Geological Survey, 1968). The length of each of the nine observation periods reflects the time span over which all data were collected, since temperature and dissolved oxygen studies were normally made on different days than were the other water quality measurements which involved more lengthy laboratory analyses. Therefore, a representative time span was assigned to each observation period.

The periods for which complete or partial water quality data were available are listed below:

(1) July 16-20, 1966. Characterized by high base flow of the stream, secondary treatment of municipal wastes, low concentration of BOD and nutrients in the stream following discharge, and with the algal environment just beginning to exert a measurable diurnal influence on the DO levels.

(2) August 2-3, 1966. Characterized by moderate base flow period, complete secondary treatment, a gradual increase in the concentration of BOD and nutrients, and an increased effect of algal photosynthesis and respiration.

(3) August 17-19, 1966. Summer low-flow period, introduction of simulated primary effluent discharged to the stream, very high BOD and nutrient loads, maximum effects of algal growth, temperature and sunlight in the assimilative reach.

(4) August 29-31, 1966. Late summer low-flow period, return to complete treatment, low BOD but continued high nutrient loads in stream following mixing at the outfall, continued high algal productivity both upstream and downstream of the discharge point.

(5) September 7-17, 1966. Fall low-flow period with continued recession of streamflow, complete secondary treatment prior to shift to partial treatment, fairly low BOD levels but higher nutrient loads in the assimilative reach, considerable background algal productivity upstream of the outfall and continued high productivity in the assimilative reach despite lower temperatures.

(6) October 6-12, 1966. Fall season, continued recession to almost zero discharge level with little or no dilution water available, effluent discharged to essentially a dry stream, partial secondary treatment, moderate BOD and high nutrient loads, continued high level of algal productivity.

(7) October 20-30, 1966. Late fall season, continued very low base flow providing little if any dilution, simulated primary effluent discharged to stream, high BOD and nutrient loads, continued high level of algal productivity.

(8) January, week 3, 1967. Winter season, very low base flow, open water to about mile point 5.0 downstream of Ames, ice cover downstream of this point, moderate BOD level, high nutrient level, depressed algal productivity due to low temperatures and/or ice cover.

(9) January, week 4, 1967. Winter season, slightly more base flow, ice cover downstream of mile point 5.0, higher BOD levels, continued depression of algal activity due to low temperatures and/or ice cover.

3. Computer program development procedures

The observed water quality levels for the 14 water quality parameters included in the output phase of the water quality simulation model became the values against which the simulated values were tested. Values of coefficients and other relationships that were determined previously using the observed water quality data were considered as invariant factors. Values of the remaining input parameters were determined by trial and error, using reasonable values gleaned from the literature or from rational consideration of maximum or minimum boundary values. An initial estimate of the several rate coefficients was made for each observation period by comparing time of flow relationships between sampling stations and associated water quality levels. Typical summary results listed previously in Tables 105 through 110 were introduced into the verification studies.

Input parameters for which no actual values or range of values existed prior to the study included: BLX, the boundary BOD contribution; DBLX, the per mile increase in BLX; BODDQ, the BOD associated with DELQX; ALPHA (α), the oxygen utilization factor for carbonaceous BOD, PCSE, the percent DO saturation of the effluent at the outfall; PSDQD and PSDQN, the percent DO saturation of the incremental change in discharge; CAALG and CBALG, the coefficient and exponent in the equation representing the increase in algal productivity due to nutrient levels; TAUTM, the algal response time for maximum productivity in the assimilative reach; PRRMX, the parameter controlling the amount of nighttime respiration in the assimilative reach; the K2ICE, and reaeration coefficient for winter season ice cover conditions.

Values for these unknown parameters were assigned and initial results were obtained. These initial results were compared with observed water quality levels for the respective observation periods, and necessary corrections introduced. The results of the initial runs also showed whether additional relationships were needed to account for the observed variations. In some instances, additional review of plant operation records was made to obtain additional values or to explain variations that occurred between observed and computed water quality levels. During the simulated primary treatment periods, for example, the trickling filter units were flooded. Plant records and field notes indicated that the effluent DO levels were very low, and were much lower than normally observed with the units in operation (75% or more). Some reaeration was permitted in the values used in the simulation runs since mixing takes place at weir of the final settling tank, in the conduit and at the outfall. However, the degree of saturation remained lower than the value used during the periods when complete treatment was in operation.

The low BOD's of the combined stream and effluent discharge in the summer period of high base flow provided an opportunity to evaluate the initial algal relationships. The oxygen requirement during these early periods was low, and it was largely immaterial whether ALPHA (α), the oxygen utilization factor, was 1.0 or a lesser value. Boundary BOD values also were studied using these summer periods.

The simulated primary effluent runs provided an excellent opportunity to test and evaluate the algal growth factors, CAALG and CBALG, the value of PRRMX, and the oxygen utilization factor, ALPHA. In this manner, the need for additional relationships frequently became evident. The need for differentiating between day and night DO saturation values in the stream (associated with DELQX) was typical of the refinements that were required to obtain adequate model reproduction of the observed results. Because little was known about the diurnal variation in DO of the plant effluent, a mean daily value was used.

4. <u>Computer results obtained with the model</u>

The results of the final simulation runs are included in Appendix F. These results include the 3 tables of detailed computer output and two plots for each of the nine observation periods. For illustrative purposes, the plots of the dissolved oxygen, BOD and ammonia profiles are shown in Figs. 79 through 84 for three of the observation periods. These are the August 2-3 (complete secondary treatment and high base flow of the stream), August 17-19 (simulated primary treatment), and for the January, third week (ice cover downstream of mile 5) periods. These results can be compared with Figs. 59, 60, 70 and 71 for the actual observed water quality levels. The final simulation runs provided general confirmation of the adequacy of the water quality model to simulate the observed water quality levels in the Skunk River.

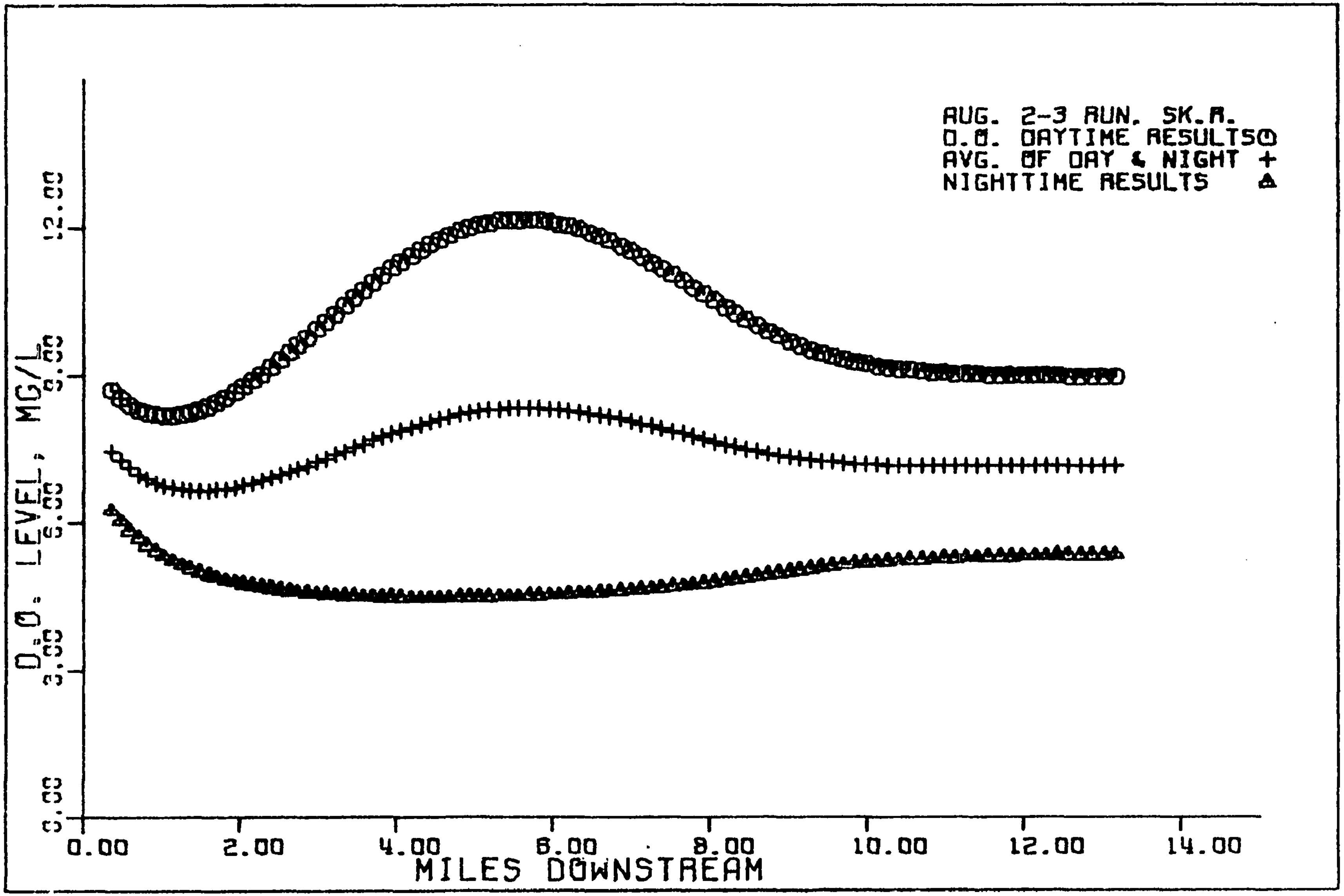

Fig. 78. Dissolved oxygen profiles for simulation of August 2-3 observation period.

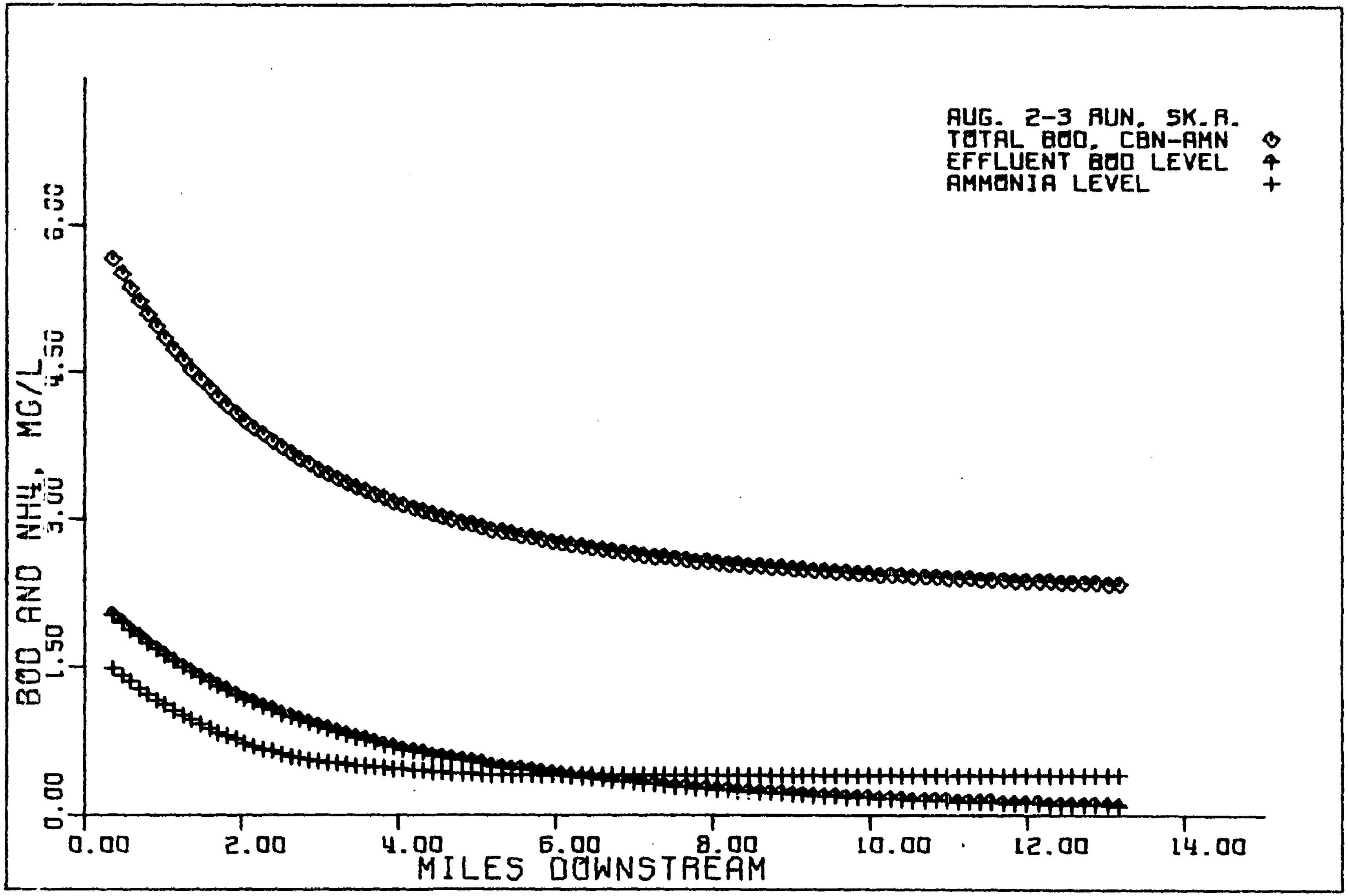

Fig. 79. BOD and ammonia profiles for simulation of August 2-3 observation period.

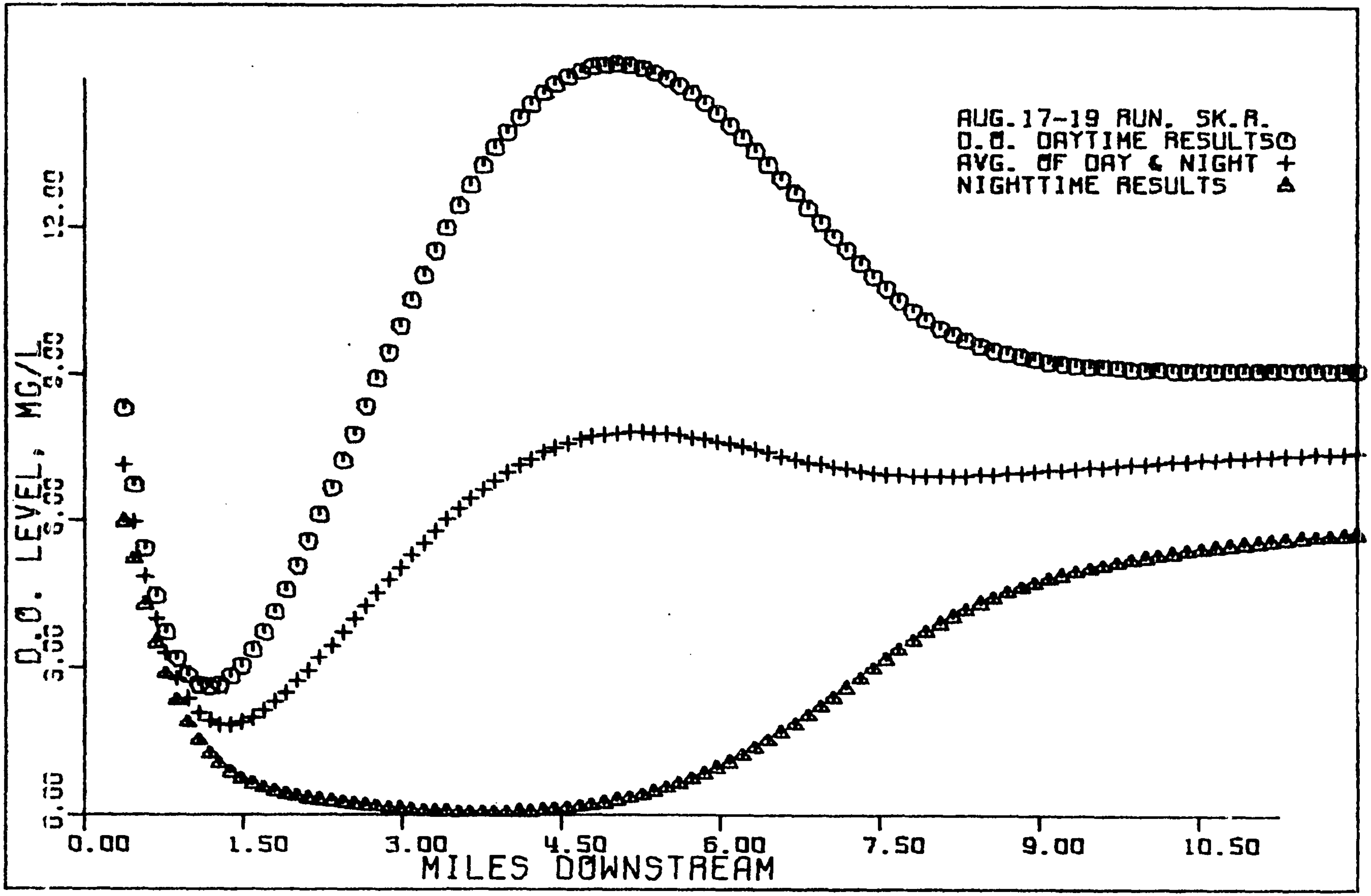

Fig. 80. Dissolved oxygen profiles for simulation of August 17-19 observation period.

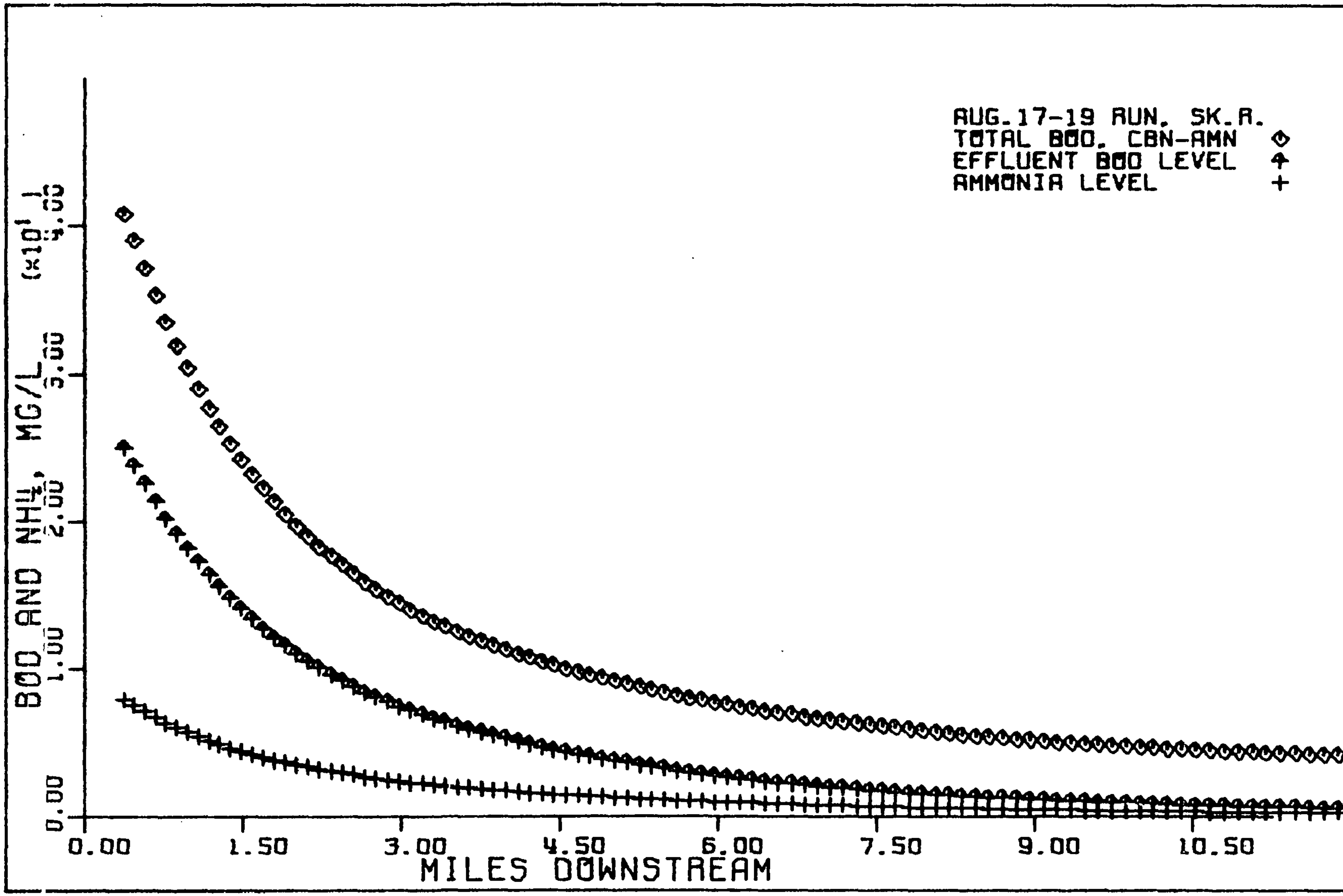

Fig. 81. BOD and ammonia profiles for simulation of August 17-19 observation period.

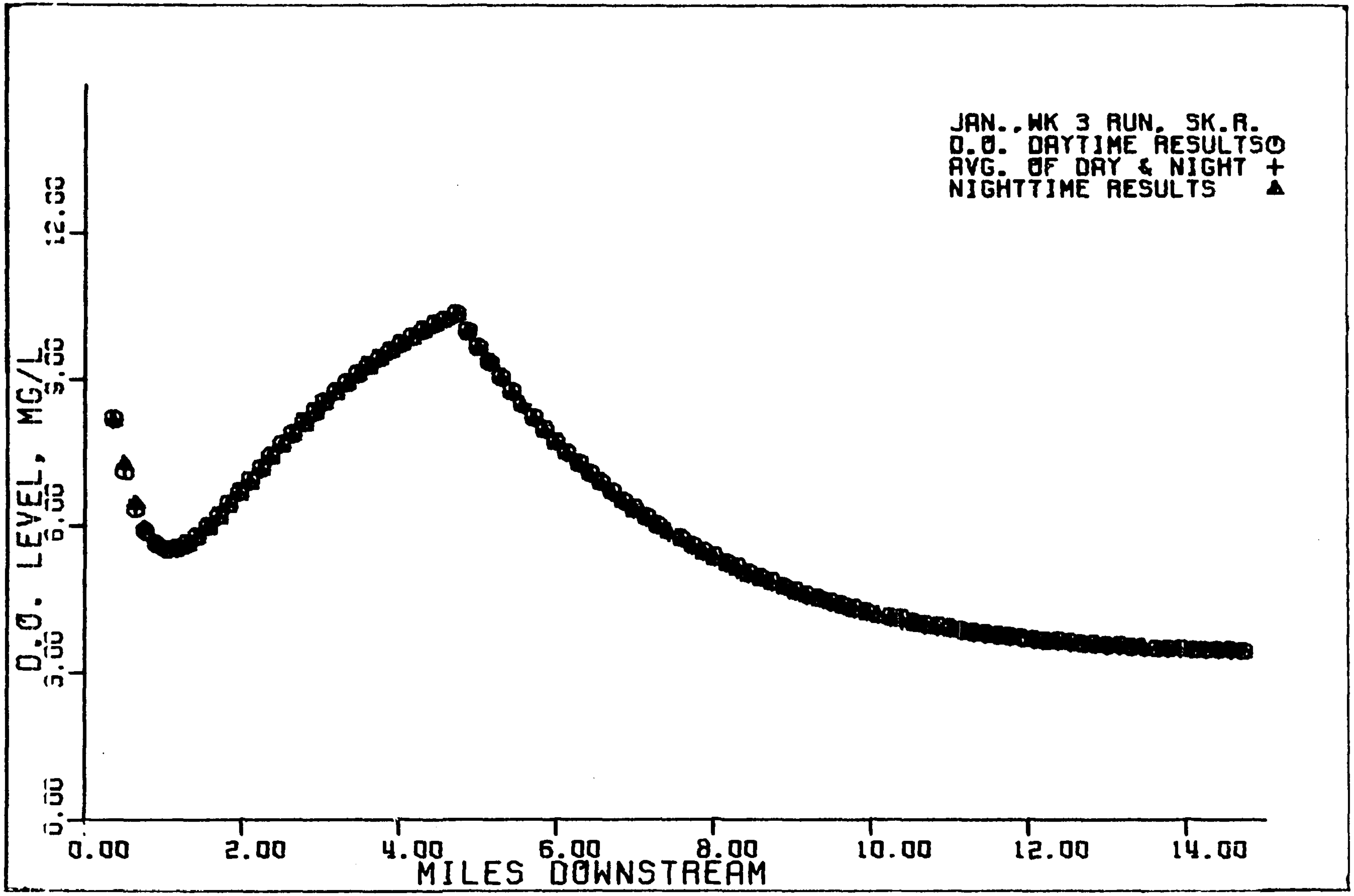

Fig. 82. Dissolved oxygen profiles for simulation of winter season observation period, January, week 3.

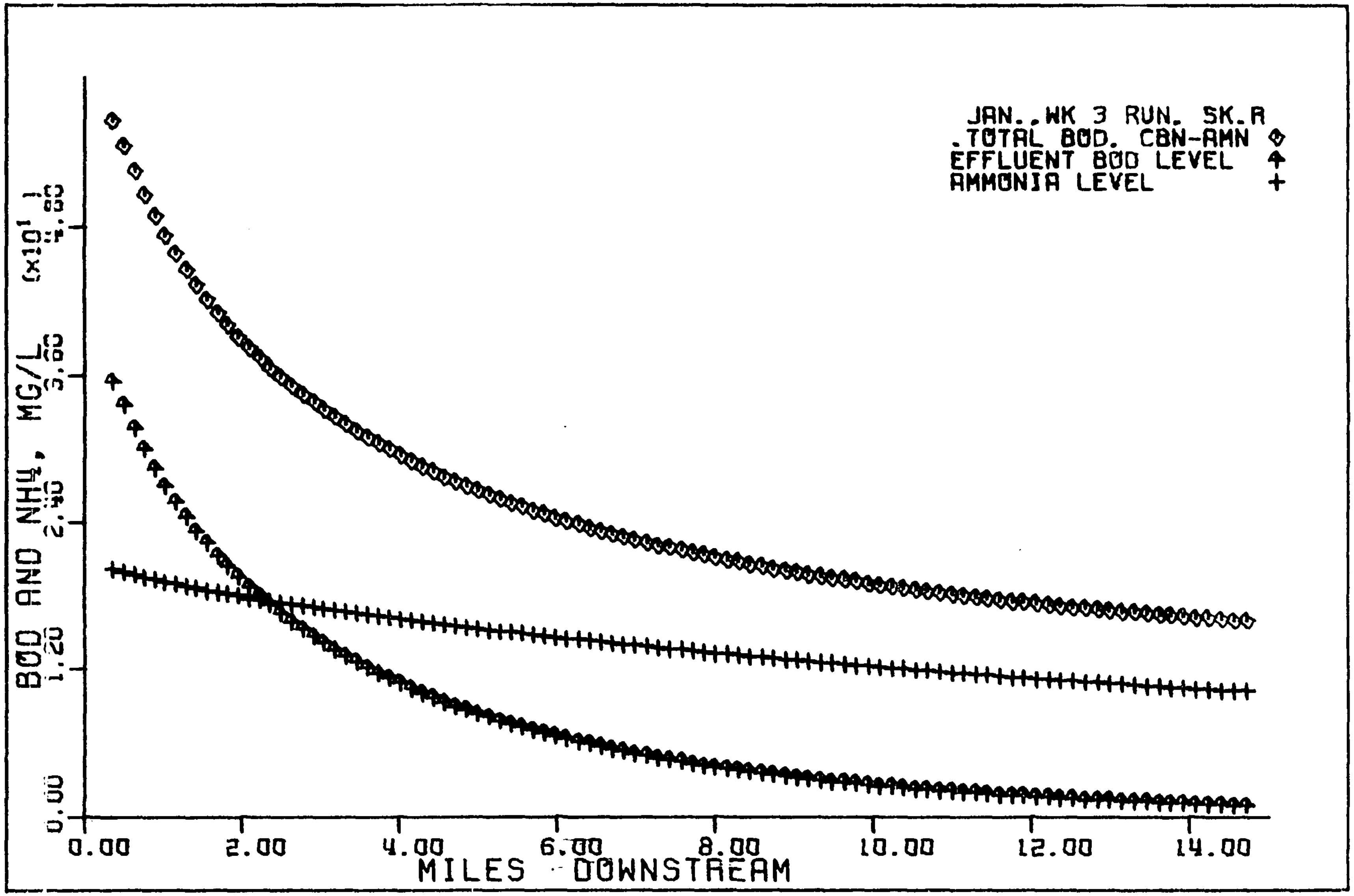

Fig. 83. BOD and ammonia profiles for simulation of winter season observation period, January, week 3.

The values of the coefficients and related water quality parameters required as input data are listed in Table 111. This matrix of input values represents the "best estimate" for each coefficient or parameter. Some values were generalized. For instance, intermediate results indicated that the point at which maximum oxygen productivity (and maximum observed DO values) occurred in the assimilative reach could be simulated best by using a TAUTM value of 0.40 with a temperature coefficient of 1.07, although with a lower coefficient, values of 0.35 to 0.60 were required for TAUTM. The values of PRRMX, although introduced on a trial and error basis, were evaluated each time to assure that the peak nighttime respiration value in the assimilative reach was equally as great as that existing upstream of the outfall (Tables 108 and 110). Once most of the coefficients and miscellaneous parameters requiring trial and error evaluation were selected, a series of computer runs were made for ALPHA = 0.1, 0.25, 0.50, 0.75 and 1.00, for each of the nine observation periods. The values of ALPHA were then selected at which optimum simulation of the observed water quality levels was obtained for each observation period. Final adjustments of a minor nature were made prior to making the final simulation runs for completion of the verification studies.

One of the primary objectives of the development phase of the water quality model was the simulation of the day and night dissolved oxygen profiles observed during the field water quality studies. Comparative statistics for both observed and computed results of the day and night DO values are summarized in Table 112. These results show that the simulation response closely approximates the observed results, considering

Table 111. Value of coefficients and other parameters used in the final simulation of observed water quality levels with the Ames water quality model

Item	Value of listed parameter or coefficient for indicated observation period								
	July 16-20	August 2-3	August 17-19	August 29-31	September 7-17	October 6-12	October 20-30	January week 3	January week 4
GAMMA1	0.90	0.80	0.72	0.75	0.80	0.80	0.80	0.87	0.78
GAMMA2	0.60	0.50	0.80	0.60	0.35	0.35	0.40	0.40	0.40
ALPHA	0.25	0.25	0.50	0.10	0.25	0.25	0.50	0.50	0.50
BETA	0.50	0.50	0.40	0.50	0.50	0.50	0.50	0.50	0.50
BLX	50.	40.	100.	60.	50.	50.	50.	40.	40.
DBLX	2.0	2.0	2.0	2.0	3.0	3.0	3.0	1.0	1.0
BODHQ	4.0	4.0	3.0	3.0	3.0	1.0	1.0	0.5	0.5
KDE	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
KDRLB	0.20	0.14	0.11	0.12	0.14	0.14	0.14	0.18	0.13
KDR	0.80	1.03	1.63	1.38	0.96	2.10	1.02	1.79	2.12
KCOLI	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
KPOR	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2	0.2
KNTR	1.5	1.5	1.5	1.5	2.5	1.5	2.0	1.0	1.0
KNR	1.5	1.5	1.5	1.5	1.3	2.5	0.3	0.3	0.2
KCTBR	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
K2ICE	—	—	—	—	—	—	—	0.4	0.4
CAALG	3.0	3.0	3.7	2.0	3.0	2.5	2.5	3.0	3.0
CBALG	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
TAUTM	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
PMR	0.4	0.8	1.3	1.5	0.8	1.3	1.1	0.5	0.5
PRRIN	1.5	1.5	2.2	2.3	1.5	1.6	1.6	1.5	1.5
PRRMX	2.2	2.5	3.0	4.0	3.2	3.2	2.4	3.0	3.0
PCSE	80.	80.	50.	80.	75.	50.	50.	75.	75.
PCSRD	110.	122.	135.	140.	120.	125.	120.	90.	78.
PCSRN	70.	65.	70.	72.	60.	60.	50.	70.	75.
PSDQD	95.	100.	100.	100.	80.	80.	80.	25.	25.
PSDQN	70.	60.	60.	65.	50.	50.	50.	25.	25.

Table 112. Comparison of observed and computed dissolved oxygen levels for the nine observation periods

Observation period, 1966-1967	Dissolved oxygen levels, mg/l, for indicated location: Daytime minimum Observed	Daytime minimum Computed	Daytime maximum Observed	Daytime maximum Computed	End of reach Observed	End of reach Computed	Nighttime minimum Observed	Nighttime minimum Computed	End of reach Observed	End of reach Computed
July 16-20	8.2	7.6	9-10	9.6	8-9	8.3	6.0^{-}	5.5	6-7	6.0
August 2-3	8.5	8.2	12-13	12.2	10.	9.2	4.9	4.5	6.5	5.2
August 17-19	1.6	2.6	16-18	15.3	8.	9.1	0.1-0.2	0.03	6.2	5.6
August 29-31	8.8	6.8	13-13.5	12.5	10.	9.6	3.3	3.1	6.1	5.6
September 7-17	6-7	5.3	10-11^{+}	12.7	9.$^{+}$	9.9	2.8	2.7	4.$^{+}$	5.5
October 6-12	0.1^{-}	0.02	14-15	15.7	14.$^{+}$	14.7	0.0	0.0	4-5	4.$^{+}$
October 20-30	0.5^{-}	0.6	13-14	13.2	13.$^{+}$	12.$^{+}$	0.0	0.3	3-4	3.$^{+}$
January, week 3										
Open water	6-8	5.5	7-9	10.4	—	—	—	5.5	—	—
Under ice cover	1-2	3.4	—	—	2.8	3.5	—	3.4	—	3.4
January, week 4										
Open water	5-6	2.3	7-8	9.6	—	—	—	2.4	—	—
Under ice cover	2-3	2.8	—	—	4.7	2.8	—	2.7	—	2.7

the complexity of the natural environment involved in the modeling process. The computed and observed nighttime values for minimum DO levels are in very close agreement. The computed and observed daytime maximum DO levels are also in close agreement, with the daytime minimum DO values showing the greatest variation between observed and computed results. Because the daytime minimums are not as critical as the night DO minimum values in evaluating waste discharges on water quality, this variation can be tolerated in the operation of the model.

The results obtained in the final simulation runs, as listed in Appendix F and summarized in Tables 111 and 112, indicate that the Ames water quality simulation model can satisfactorily reproduce the observed water quality levels observed in the stream environment. Inspection of Table 111 indicates that the summer and fall observation periods are reproduced more accurately than are the winter periods. The winter conditions pose more of a problem, since there are several miles of open water during low-flow periods before the temperature of the combined effluent and stream discharge reverts back to the freezing mark. Additional analysis and field studies of winter conditions appeared desirable.

5. Additional evaluation of winter conditions

The results listed in Table 111 indicated that the oxygen utilization factor, ALPHA (α), for carbonaceous BOD ranged from 0.10 to 0.50. For the summer period, an average of 0.30 was obtained. If the two periods of simulated primary effluent are neglected, then a value of 0.25 appears most frequently for the summer and fall periods. Because winter conditions appear to be critical, with the loss of reaeration ability if thick ice and snow cover occurs, additional evaluation of the relationship between ALPHA and K2ICE was considered necessary. Additional computer runs were made for both observed winter periods, using ALPHA = 0.25 and K2ICE = 0.2.

Additional dissolved oxygen data were obtained in January 1969, during a study of low-flow conditions, as a continuation of work reported by Sendlein and Dougal (1968). The data are listed in Table 113. The stream discharge varied from 40 to 63 cfs in the assimilative reach located between Ames and Colfax. The stream was completely frozen over upstream of the gaging station at mile point 0.0, although there was some open water at the overflow weir at the upper gaging station above Ames. Open water was observed from the plant outfall to a point some 4 mi downstream. The ice cover in the reach from Cambridge to Colfax was thick, being from 6 to 12 in. in thickness and with some snow cover overlying the ice. These conditions varied somewhat from the January 1967 series of observations in that during the former period the ice was thinner in the downstream reaches and there were air pockets between the water and the underside of the ice. The values listed in Table 113 show that even at high winter stream discharges, oxygen depletion is severe. The minimum values recorded at the downstream stations, 2.8 and 2.2 mg/l, show that values less than the desired 4 mg/l for fish and aquatic life currently exist under the thick ice cover. The minimum sag point was not identified, although the values indicate that a level of about 2 mg/l might be approximated.

Table 113. Dissolved oxygen values obtained during the winter season, January 1969, for additional confirmation of oxygen depletion

Station	Location	Mile	Dissolved oxygen, mg/l	Measured discharge, cfs	Observation notes
SK-1	Ames	0.3	10.0	40.6	Ice cover
SK-4	Below Ames	2.9	9.7	49.0	Open water
SK-9	Cambridge	11.0	5.2	54.7	Ice cover
SK-14	Elkhart	19.6	2.8	54.3	Ice cover
SK-17	Above Colfax	29.0	2.2	63.0	Ice cover

The three additional winter season computer studies were made using the lower values of ALPHA and K2ICE listed above. The 1970 estimated conditions (1970 status) which had been tabulated for computer analysis were used to simulate the winter 1969 DO profile. This simplification was introduced because detailed river and pollution control plant data were not readily available, and it was evident that the results obtained using the 1970 data would actually represent a more severe situation, Dissolved oxygen levels would be higher for conditions of less stress, as represented by actual 1969 conditions.

The results of these additional winter studies are included in Appendix F. A summary of the DO levels for the three winter observation periods are listed in Table 114. The results indicate that the value of ALPHA is at least 0.25 in winter periods, and the the reaeration coefficient under thick ice and snow cover may be as low as 0.20. The 1969

Table 114. Results of additional winter analysis of dissolved oxygen levels using the water quality model[a]

	Dissolved oxygen levels for indicated observation period, mg/l						
	January 1967 week 3		January 1967 week 4		January 1969		
Mile	Observed	Computed	Observed	Computed	Observed	Computed K2 = 0.2	Computed K2 = 0.3
0.0	12.5	11.4	11.0	10.9	10.0	10.3	11.6
0.4	9.2	8.2	5.5	7.9	–	10.0	11.5
1.8	6.6	8.2	–	–	–	10.4	11.1
2.9	4.4	9.8	7.5	8.6	9.7	10.7	11.1
6.5	–	–	5.8	8.5	–	9.2	9.5
11.0	1.6	4.5	2.4	4.4	5.2	6.2	6.8
19.6	2.8	2.9	4.7	2.8	2.8	3.7	5.0
29.0	–	–	–	–	2.2	2.8	4.7

[a]Analysis using ALPHA = 0.25, IWTRA = 3, and K2ICE = 0.2 except where indicated, with computed values expressed as daily averages.

DO profile for the severe cover conditions observed in the field is closely approximated with these values. The results show that the reaeration coefficient of 0.20 may be too severe a value for the other two winter periods; however, the simulation runs ended before the minimum sag point was reached. It was concluded that the adoption of 0.25 for ALPHA and 0.20 for a minimum value of K2ICE was justified for such severe winter conditions. The value of K2ICE, the reaeration coefficient under ice and snow cover, will be in the range of 0.2 to 0.4 for all practical purposes. The effect of relaxing the reaeration coefficient to the 0.3 value is illustrated in Table 114. The actual minimum oxygen sag was reached at a DO level of about 4.7 mg/l. This indicates that the minimum DO level drops about 2 mg/l for a decrease in the winter reaeration coefficient from 0.3 to 0.2, based on the reduction of DO from 4.7 to 2.8 mg/l.

6. Discussion and summary

The verification studies, as indicated by the computer results and the summary tables, show that satisfactory results can be obtained with the ISU water quality simulation model. The algal productivity and its related influence on the dissolved oxygen resource are expressed adequately by Eqs. 126 through 130. Comparison of observed and computed dissolved oxygen levels shows them to be in close agreement. The remaining water quality parameters as computed, including the carbonaceous and nitrogenous BOD and nutrient levels, conform reasonably well with observed values.

The computer results and the values summarized in Table 111 were studied for general relationships, and for seasonal variations. Values adopted for forecasting future conditions are listed in Table 115. Seasonal variations were introduced if they were considered justified. The gradual growth, development, and intensification of the ecological habitat including the algal environment during the summer, fall and winter seasons justifies some seasonal variations in selected parameters. For others, insufficient knowledge prevents such determination at this stage of development of response models.

Most of the selected values were reviewed briefly to assure that reasonable values were being obtained through the trial and error

Table 115. Values of coefficients and other parameters adopted for forecasting water quality levels in the future

Item	Any season	Value for indicated month or season: Summer, August	Fall, Sept.	Late fall, Oct.-Nov.	Winter season
GAMMA1	0.80				
GAMMA2	0.60				
ALPHA	0.25				
BETA	0.50				
BLX		50.0	60.0	70.0	40.0
DBLX		2.0	3.0	3.0	1.0
BODDQ		3.0	2.0	1.0	0.5
TEMPE		70.0	65.0	60.0	50.0
PCSE		75.0	75.0	75.0	75.0
PCSRD, 2-yr freq.		115.	120.	125.	95.
10-yr freq.		120.	125.	130.	90.
PCSRN, 2-yr freq.		80.	75.	70.	75.
10-yr freq.		75.	70.	65.	70.
PSDQD, 2-yr freq.		105.	110.	115.	50.
10-yr freq.		105.	110.	115.	50.
PSDQN, 2-yr freq.		70.	65.	65.	50.
10-yr freq.		60.	55.	50.	50.
KDE	0.08				
KDRLB	0.14				
KCTBR	2.5				
KCOLI	2.5				
KPOR	0.5				
KNTR	1.5				
KNR	1.5				
KDR	Eq. 120				
K2R	Eq. 121				
K2ICE					0.2-0.4
IWTRA, condition					3

verification concept. The boundary BOD contributions, for example, ranged from 40 to 100 lb per mile per day. These values appear reasonable in comparison to the effluent BOD load of about 800 to 2,600 lb per day listed in Table 44 for 1967. The range of values selected for forecasting purposes is increased from summer to fall to reflect the end of the growing season and influx of dead and dying vegetation to the stream. A reduction is permitted in the winter season, reflecting the ice cover effect of sealing off the air-water interface.

The effluent temperatures were selected to vary during the various months of the summer and fall seasons, with a still lower temperature for winter conditions. The stream DO saturation values will normally vary seasonally, as influenced by the algal seasonal growth pattern. The phosphate, ammonia, and nitrate coefficients were made more temperature dependent in the mathematical model when the average coefficient values were adopted. This was accomplished by assigning a value of 1.08 to the temperature coefficient factor. The remaining parameters and coefficients were selected on the basis of observed river quality data or on additional study of plant operation records or other sources.

The maximum algal productivity is expressed by the term (Eq. 127):

$$\frac{dO}{dt} = (1 + \sigma) \times \text{PMRIN}$$

$$= \text{CAALG} \times (\text{PO4})^{\text{CBALG}} \times \text{PMRIN}.$$

The net oxygen production approached a level of 5 to 6 mg/l/hr in the observed runs. This range was much greater than values obtained in the published literature. However, Eller and Gloyna (1969), in a study of oxygen production and loss in a model river (laboratory flume), recorded peak values of 4 to 6 mg/l/hr. Therefore, it appears that reasonable values are being obtained with the mathematical model.

Adoption of these values provides the last input control data for the ISU water quality model prior to using it as a forecasting tool. The municipal raw sewage and effluent conditions, as discussed in previous chapters, provide the additional plant data required for this final phase. Forecasting of the 1970 status and of the 1990 design level will be considered next.

F. Forecasting the 1970 Status of Water Quality in the Skunk River

1. Selection of 1970 input values for water quality

Additional familiarization with the ability of the ISU water quality model to simulate stream water quality was considered necessary prior to applying it to future design conditions. It appeared desirable to obtain an estimate of the 1970 status of water quality in the Skunk River at Ames which could serve as the basis for design of the proposed expansion of the water pollution control plant. For these reasons, the 1970 status was introduced as an intermediate step between the simulation studies of observed stream conditions in the past and the forecast of future design conditions.

The plant loadings, treatment levels, and plant efficiencies for 1970 and other future periods were estimated previously, and tabulated in Chapter VI. Values for summer and winter were used in the 1970 status study. The treatment plant efficiencies were estimated using Eq. 107. A summer efficiency of 70% and a winter efficiency of 65%

were permitted. These values represent the combined carbonaceous and nitrogenous BOD_5 values, which must be separated for use in the model. The carbonaceous BOD_5 was estimated as 60% of the total, giving 40 mg/l BOD_5 in the summer and 60 mg/l in the winter The total BOD_5 was approximately 70 mg/l in the summer and 100 mg/l in the winter. These values represent a severe loading on the existing stream, but not excessive in view of the age of the plant and the fact that its original design capacity has been exceeded.

Nutrient levels in the effluent were based on the results of the field studies and the computer simulation results. Progressively less nitrification of the plant ammonia loading was assumed for the summer-fall-winter sequence used in the study. The values used for ammonia ranged from one-half in the summer (of a total of 25 mg/l) to one-sixth in the winter (of a winter total of 30 mg/l in the raw sewage). These values represent the effect of increased loadings on the present plant in reducing the nitrification normally achieved with the trickling filter process. Phosphate values assigned for this phase of the studies were 25 mg/l in the summer and 30 mg/l in the winter. Both ammonia and phosphate loadings in the raw sewage were based on the experienced values listed in Table 44. Analysis of these data indicated that for the assigned 0.18 pcd of BOD_5 per population equivalent, a value of 0.018 pcd for ammonia nitrogen and for phosphates could be adopted. If the amount of phosphates in household detergents changes in the future, then these current values may need to be changed, since much of the phosphate content is from a detergent source. Although the total phosphate content is made up of orthophosphates, polyphosphates and the organic phosphates in the human feces, it is presumed in the mathematical analysis made herein that the assigned values represent the effective phosphate levels in the effluent that contribute to the development of a productive algal environment. Additional research is needed to separate and categorize the role of these several forms in terms of the response of the stream environment and of their fate in the stream.

Other parameters, for stream and pollution control plant conditions, have been listed previously and will not be repeated here. Both the 2-yr and 10-yr frequency levels for low-flow conditions (Table 81) were used in the 1970 status study. This provided an opportunity to compare more frequent but higher stream discharge levels (associated with the 2-yr event) with the less frequent but more severe 10-yr conditions.

2. Results of the 1970 water quality status study

Computer results and plots of the 1970 status study are included in Appendix G. Results for the several seasons [summer (August), early fall (September), late fall (October to November), and winter] are included for both the 2-yr and 10-yr low-flow frequencies. Results for the winter conditions include runs with the winter reaeration coefficient, K2ICE, having values of 0.2 and 0.3. This comparison provides an initial measure of the sensitivity of winter conditions on the water quality levels, especially the dissolved oxygen resource of the stream.

A summary of the computer results, which involved 8 separate analyses for the four periods and 2 low-flow frequencies, is included in Table 116. For illustrative purposes, the computer plots for the

Table 116. Water quality levels for the 1970 status study of the Skunk River at Ames, Iowa[a]

Month or season	Frequency of low flow	Minimum daytime DO, mg/l	Maximum daytime DO, mg/l	Minimum nighttime DO, mg/l	Maximum ammonia level, mg/l-N	Maximum phosphate level, mg/l
August	2-yr	6.9	12.9	3.8	2.9	5.8
	10-yr	3.2	11.3	0.7	7.2	14.8
September	2-yr	6.3	14.9	0.9	5.8	9.5
	10-yr	2.2	12.7	0.0	11.2	18.6
Oct.-Nov.	2-yr	5.2	15.4	0.8	10.1	17.7
	10-yr	1.7	13.0	0.0	14.9	21.9
Winter, K2ICE = 0.3	2-yr	1.5	9.0[b]	1.4[c]	14.9	17.9
	10-yr	0.0	7.2[b]	0.0[c]	23.0	27.6
Winter, K2ICE = 0.2	2-yr	0.31	9.0[b]	0.27[c]	14.9	17.9
	10-yr	0.0	7.2[b]	0.0[c]	23.0	27.6

[a]Summary of runs included in Appendix G.

[b]Value occurs in open water just prior to start of ice cover.

[c]Actual secondary oxygen sag value that occurs under ice cover (see plots in Appendix G).

summer (August) and winter seasons, 10-yr frequency level, are included herein as Figs. 85 through 88. It should be noted that the fall season results give lower nighttime DO values, but only the August plots are included here as an illustration of the range of DO levels that will be experienced from summer to winter. The winter conditions are the more

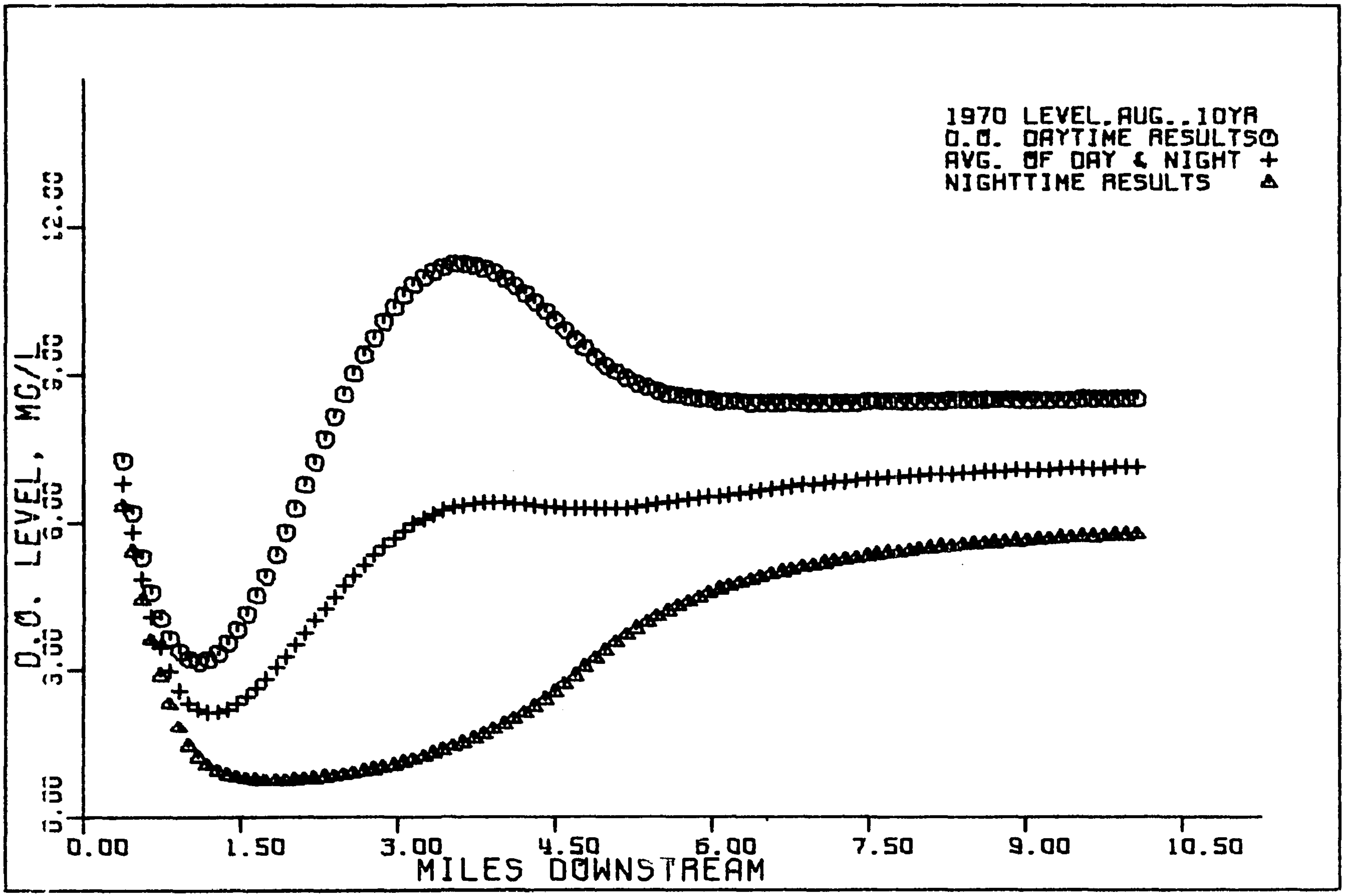

Fig. 84. Dissolved oxygen profiles for the 1970 status study, summer season (August) conditions.

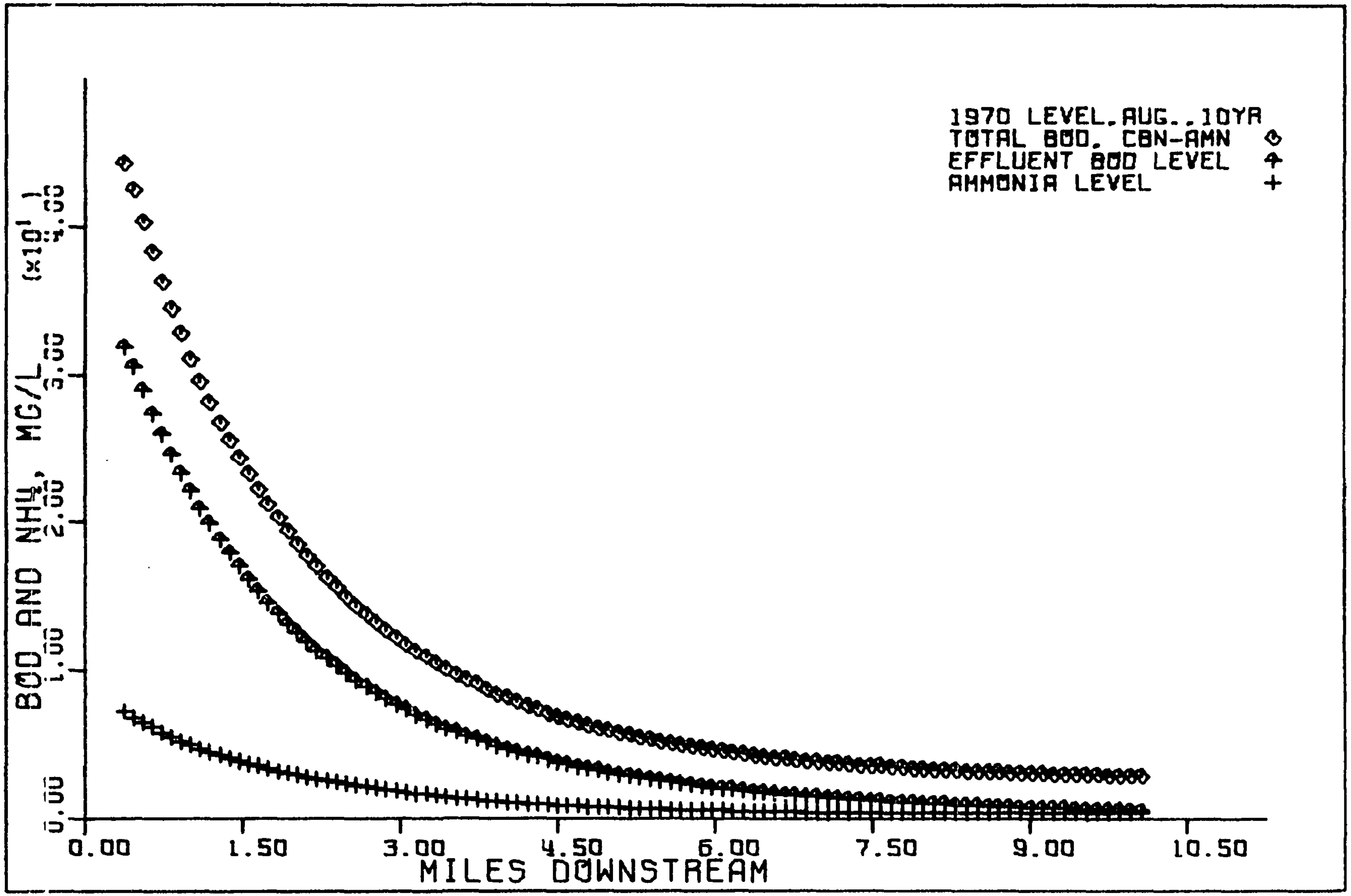

Fig. 85. BOD and ammonia profiles for the 1970 status study, summer season (August) conditions.

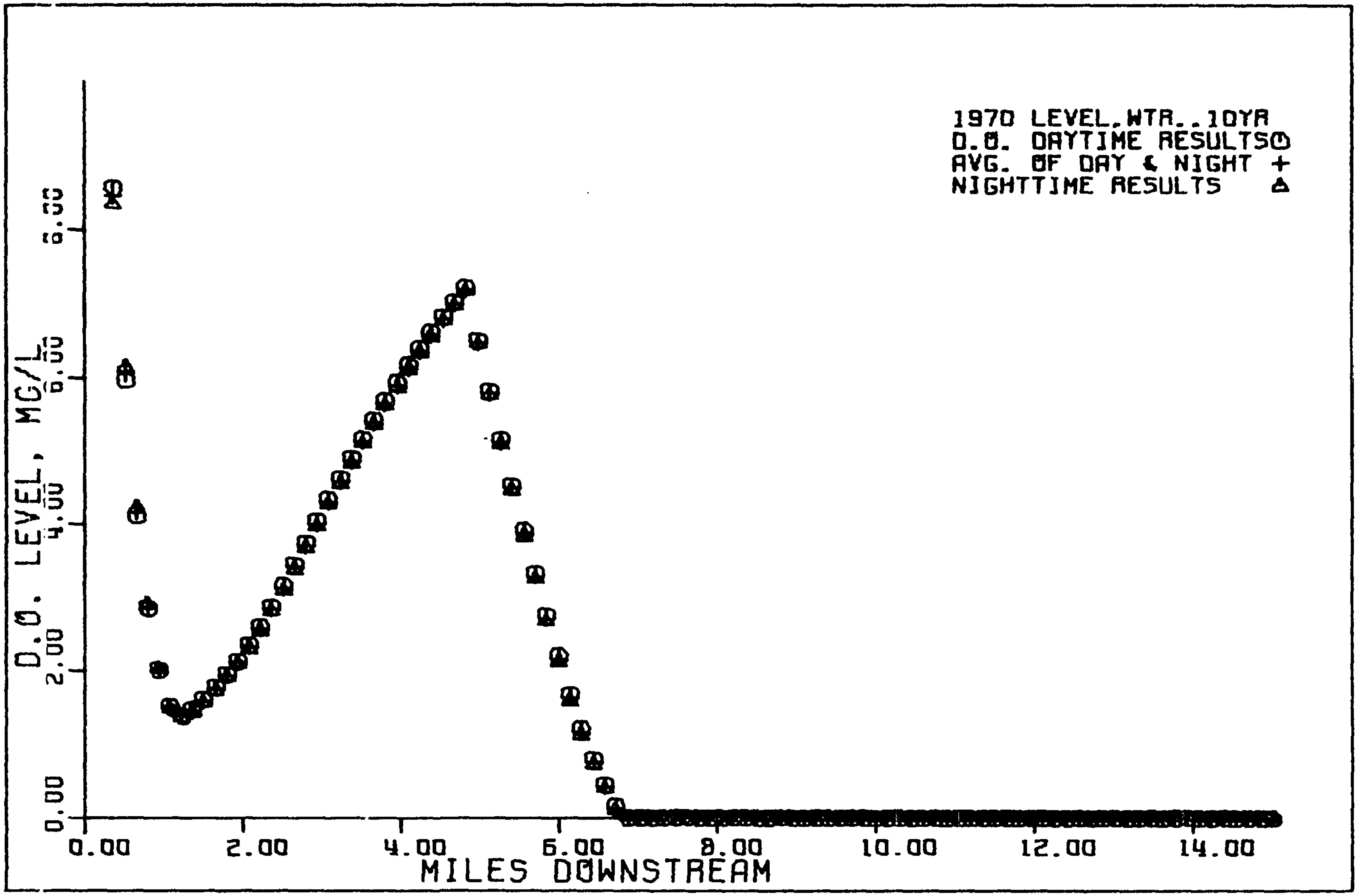

Fig. 86. Dissolved oxygen profiles for the 1970 status study, winter season conditions.

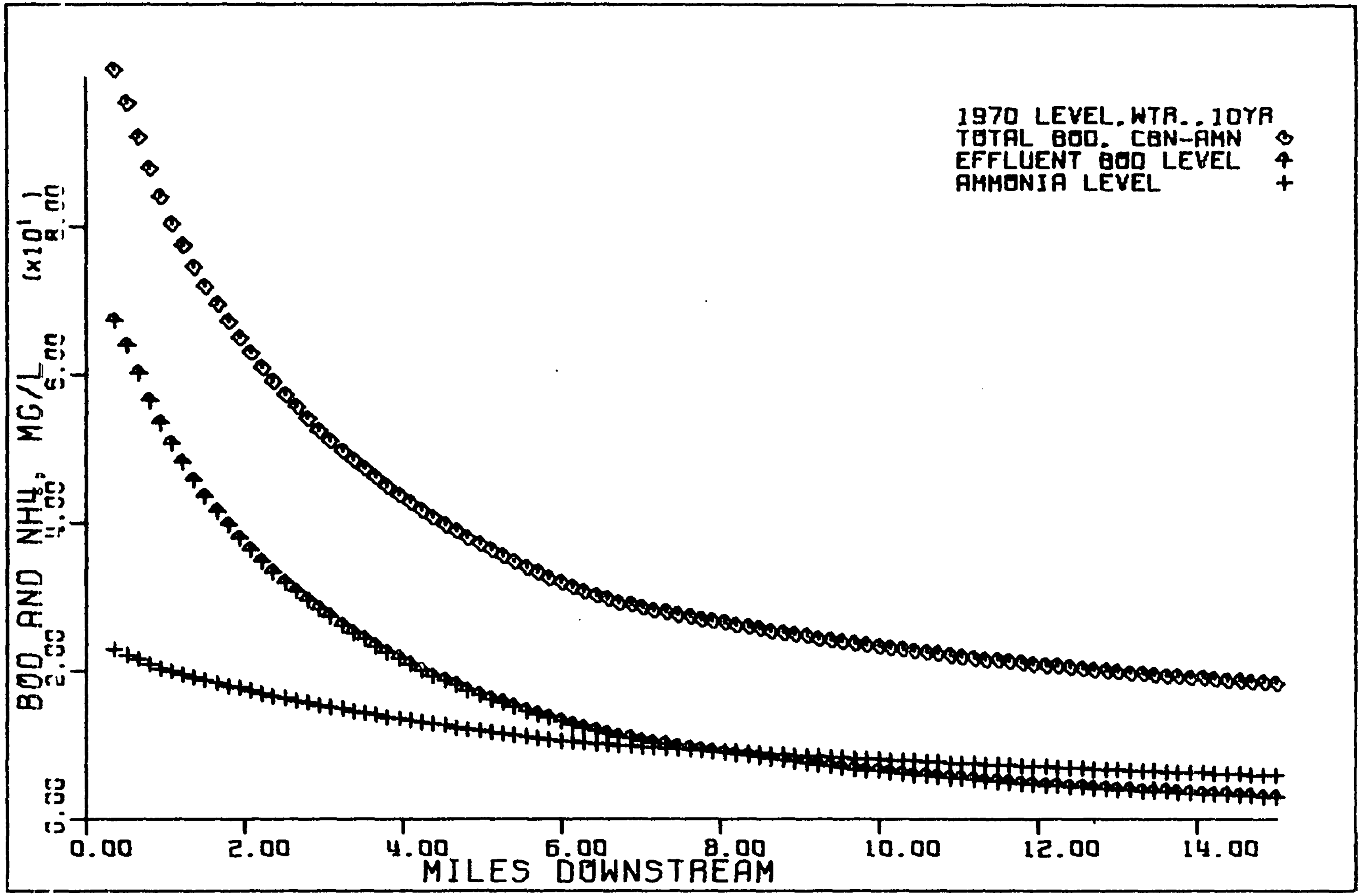

Fig. 87. BOD and ammonia profiles for the 1970 status study, winter season conditions.

severe, and will usually dictate the maximum amount of low-flow augmentation that will be required, if available.

3. Discussion and summary

The results contained in Appendix G and summarized in Table 116 show that the water quality model operates satisfactorily in a forecasting role. The deoxygenation coefficient, K2R, is computed from the actual BOD_5 levels after mixing in the stream (Eq. 116). The characteristic DO profiles are obtained, and are more accentuated (for the 1970 status) than are the observed DO results (1966) since the BOD loadings and nutrient values are higher. Progressively lower water quality levels are reached as the seasonal sequence continues from summer to late fall and to winter conditions for all of the DO boundary values listed in Table 116. This is caused by the increase in nutrient levels (for the increase in maximum daytime DO levels) and the increased concentration of BOD with lower streamflows (for the lower minimum DO levels) as the seasonal sequence progresses. Increased algal respiration is an additional nighttime factor.

Although the maximum daytime DO levels increase from summer to fall, reflecting the increased oxygen productivity with continued algal growth, the 2-yr values are higher than the 10-yr maximum daytime values. The opposite effect should be expected, based on observed field conditions. In the ISU water quality model, the effect of increased BOD concentrations, as the stream discharge decreases seasonally, depresses the DO levels more than the algal oxygen productivity increases them. Thus, it appears that perhaps the model should be made more responsive to increased nutrient levels. This would require increasing the value of the exponent CBALG, and/or introducing a seasonal or frequency variation in the coefficient CAALG. This improvement can be considered in future use of the model, but is not considered essential at this phase because the relative difference between 12 and 15 mg/l DO concentrations is not important when compared to the desirable minimum of 4 mg/l for the aquatic habitat. The daytime and nighttime minimum values are lower for the 10-yr event, and this simulation is the more important of the two extremes.

The 1970 status study shows that in the assimilative reach the minimum DO levels are less than the desired 4 mg/l specified in the Iowa standards, for all periods except the summer and fall 2-yr frequency periods. Winter conditions are especially severe, and, at the 10-yr frequency level, the stream would be devoid of any dissolved oxygen. The model cannot be operated sufficiently long to evaluate the winter recovery of DO, unless the time increment DTIM is increased. Until additional sensitivity analyses can be conducted to evaluate the effect of changing the time increment, use of a maximum of 0.01 day in the summer and 0.02 day in the winter season is recommended to reduce the error inherent in applying the differential equations on a step basis through the related time-space increment.

At the 2-yr frequency level, the minimum DO levels are low, but some oxygen is available in all parts of the assimilative reach. Thus, the fish and other life have an opportunity to survive. However, the 2-yr frequency event is a commonly experienced event, having a 50%

chance of occurring in any 1 yr. The levels of nutrients and coliforms also are high. The ammonia concentrations are above 5 mg/l for all conditions except the August 2-yr event. The computed phosphate levels are even higher, and confirm the development and existence of a highly productive algal environment. Coliform levels (Appendix G) are also high, as expressed in percentage terms.

The 1970 status study confirms the usefulness of the Ames water quality model in simulating observed water quality levels and in forecasting water quality levels for other periods in the future. The fact that reasonable estimates were obtained for the 1970 status conditions, in view of the known effluent loads, provides additional confirmation of its adequacy to predict. The model now provides an opportunity to simulate and forecast the response of the stream environment to the discharge of waste effluents under a variety of future loading conditions and treatment alternatives.

The Skunk River, with poor natural low-flow characteristics, is severely stressed by the discharge of effluents from the existing water pollution control plant at Ames. Improvements in the plant facilities are required if water quality levels are to be "enhanced." The role of the proposed Ames Reservoir in achieving water quality control must be explored as a physical and economic alternative in providing an improved level of waste treatment.

G. Forecasting Water Quality Levels for the 1990 Design Period

1. Forecasting for future alternatives

Analysis of future water quality control and waste treatment alternatives which exist in the physical and economic sense can now be made, using the ISU water quality model. Only a few alternatives will be explored in this study; additional studies will be recommended for future research. Those physical alternatives which lead to economic analysis include, for the Skunk River case study,

1. trickling filter secondary treatment,
2. activated sludge secondary treatment,
3. lagoons for temporary storage and/or tertiary treatment, and
4. reservoir storage as a low-flow augmentation alternative (from the authorized Skunk River dam and reservoir).

Either of the first two alternatives suffices for secondary treatment, with the latter two being supplementary alternatives in the goal to enhance the water quality in the Skunk River at Ames.

2. Selection of the design period

Expansion of the water pollution control plant at Ames can be accomplished in one of several ways. Complete plant relocation (in view of the nearness of the plant to relocated U.S. No. 30 which is one of the principal entrance routes into the city) will not be an issue in this study. However, in terms of land use, esthetics, and competition with urbanization of the surrounding area, the existing location no longer offers the remoteness which existed at the time of plant construction in the early 1950's. Residential developments south of the plant encourage recreational use of the stream in both summer and winter, with a potential for body contact. The need for chlorination of the plant effluent needs to be evaluated in conjunction with plant relocation, but since chlorination has never been practiced or required at the existing plant, these additional problems will not be considered herein.

In times of rapid population growth, plant expansion might best be accomplished using short design periods. Perhaps 5-yr or 10-yr increments would be advisable, depending on the type of facilities proposed and of their being adaptable to stage construction. During periods of inflationary prices, however, this time sequence may be of little economic advantage. To simplify the present analysis, a 20-yr design period was selected. If the proposed plant expansion is designed to accommodate the projected 1990 population adequately, it may suffice on an overload basis to serve Ames to the year 2000. This concept will be used in the remainder of the case study, especially in view of the population lag characteristics noted previously. This agrees closely with the results of the population studies presented in an earlier chapter.

The 1990 population estimates and projected water demand and waste water volumes were used in the forecast study. The effluent discharge predicted is 7.2 mgd for the summer season and 5.9 mgd for the winter season. The population equivalent for design purposes is 79,000 to 80,000, providing a raw sewage BOD_5 load of 14,300 lb per day (carbonaceous BOD). As stated in the 1970 status study introduction, the nitrogen and phosphate levels are assumed to be one-tenth each of this BOD_5 loading. The concentration of carbonaceous BOD_5 is therefore about

240 mg/l in the summer season and 290 mg/l in the winter period. These values establish the organic loading and nutrient concentrations for the ensuing water quality studies.

3. Technical alternatives

In considering the alternatives which are available for achieving water quality control and enhancement, it was determined in a preliminary analysis that low-flow augmentation using the authorized Ames Reservoir was a necessary element in all studies. This acceptance of low-flow augmentation was made for three reasons. First, the hydrologic study revealed that the natural low-flow characteristics are so poor that at the 7-day, 10-yr frequency level the stream is practically dry. A high level of tertiary treatment is an obvious requirement unless low-flow augmentation is provided. Extensive analysis of tertiary treatment methods, alternatives, and economics would be required under the present state of the art. This was beyond the scope and purpose of the case study.

Second, the 1970 status study that was made using the Ames water quality simulation model indicated that the predicted water quality was below the established Iowa stream water quality standards on several bases. Since the plant is overloaded at present, the mass of waste loads discharged to the stream now is comparable to the projected 1990 effluent loads because of the projected additional population growth. Therefore, it is impossible to improve the water quality levels of the stream for the projected 1990 design conditions by normal secondary treatment processes.

Third, the present study can be made in an advantageous manner using low-flow augmentation as a basic requirement for general improvement of the stream for beneficial use. Consideration of other alternatives in future studies can then be made on a comparative basis with the low-flow augmentation requirement to test the economics of alternative measures of accomplishing equal or higher levels of water quality. If alternative treatment methods can accomplish the same result at less cost, they can then be proposed for consideration.

4. Alternative design conditions selected for study

a. Study methods Several technical alternatives for water pollution control were studied in detail, relying on the low-flow augmentation concept and using established secondary treatment methods principally. The following combinations were studied:

(1) Trickling filter and low-flow augmentation, 10-yr frequency level, 50 cfs release rate.

(2) Activated sludge and low-flow augmentation, 10-yr frequency level, 50 cfs release rate.

(3) Activated sludge, low-flow augmentation, and a tertiary storage and assimilation lagoon; 10-yr frequency level, 50 cfs release rate from the reservoir, one-half of effluent stored during the winter period.

(4) Trickling filter and low-flow augmentation, 10-yr frequency level, but increased winter release rate of 100 cfs.

Studies of the first two categories were made for the seasonal sequence used in the 1970 status study. These included summer (August), early fall (September), late fall (October-November), and winter periods with ice cover on the stream. Two winter reaeration coefficients were used in the winter period for the first two study categories, K2ICE = 0.2 and

0.3. Computer runs were made for the winter periods only in the last two categories, to illustrate the need for selecting additional alternative treatment or control measures to solve the winter stream problems associated with ice cover and a low reaeration capacity.

b. Criteria for the trickling filter alternative The water pollution control plant efficiency for continued trickling filter secondary treatment was assumed to be 90% in summer and 85% in winter. This gives an effluent carbonaceous BOD_5 value of 24 and 44 mg/l in summer and winter, respectively. The proportion of ammonia nitrification (ammonia versus nitrate concentration) for optimum plant operation was assumed to be: August, 5 mg/l ammonia and 20 mg/l nitrates; September 10 and 15; October-November, 12.5 and 12.5; winter, 20 and 10, respectively. The DO concentration in the effluent was assumed to be 75% of saturation. The other factors and coefficients required for input have been listed in previous sections. These include the stream temperatures and increases in discharge in the downstream condition, for the 10-yr frequency level.

c. Criteria for the activated sludge alternative The efficiency of an activated sludge plant was based on renovating the existing water pollution control plant and introducing complete utilization of the activated sludge process. Precise details of accomplishing this were not studied; the existing trickling filter units might be used as roughing filters or the rock might be removed and the tanks converted to aeration units.

The overall plant efficiency adopted for the activated sludge process was 95% in the summer and 90% in the winter. These values were based on the study of the effluent obtained at the Marshalltown activated sludge plant and on additional review of the Marshalltown plant records. These efficiencies give an effluent carbonaceous BOD_5 of 12 mg/l and 29 mg/l in summer and winter, respectively. In this study, the nitrification of ammonia will be suppressed in the usual operation of the activated sludge plant, primarily due to low DO levels in the aeration units. The relative levels of ammonia and nitrates assumed for analysis were: August, 20 mg/l ammonia and 5 mg/l nitrates; September, 20 and 5; October-November, 20 and 5; and winter, 25 and 5. Even less nitrification might be experienced, but the values listed appear to be reasonable for typical plant operation. The DO concentration in the effluent was assumed to be 25% of saturation at the outfall, reflecting the low DO levels in the aeration tanks.

d. Additional criteria for the tertiary lagoon This alternative was introduced to illustrate a simple means of improving water quality in the stream in the winter period. It was assumed that a tertiary lagoon of sufficient size and suitable design to serve the designated purposes would be from 80 to 100 acres in area, and would be constructed in cellular units. During the summer period, including early and late fall, it could be operated as an assimilative lagoon, providing at least 8 to 10 days detention at 2 to 3 ft depth. This should nitrify most of the ammonia, although additional aeration might be needed. The literature review indicated that little ammonia would be nitrified in winter in lagoons or waste stabilization ponds. Therefore, for model analysis herein, it was assumed that one-half of the effluent would be discharged to the stream directly (thus assuring that its quality content is known) and the other half would be stored temporarily for up to 3 months. The tertiary lagoon system would be designed for a surcharge of 8 to 10 ft to accomplish this purpose.

Converting the existing Ames water pollution control plant to the activated sludge process would make the lagoon alternative feasible, since the raw sewage is pumped to a relatively high elevation into the primary settling units. There is sufficient elevation difference, between (1) the high ground and primary settling units and (2) the flood plain, to permit surcharging the lagoons by gravity flow during the winter period. Sufficient land is also available in this area, and has been purchased for use by the city of Ames for plant expansion.

It is difficult if not impossible to forecast the water quality which would be discharged as effluent from the lagoon system in the summer period. Characteristically, the effluent of lagoons serving activated sludge systems has had a higher BOD_5 than the influent. However, the tradeoff of bacterial (animal) BOD for plant (algae and plankton) BOD might be assumed to be of considerable value, and if coliform counts are reduced and the ammonia is nitrified there is much to be gained. Most studies have shown, however, that removal of the plankton and algae should be accomplished if a good effluent is to be discharged to the receiving stream. These additional complications will be assumed away in this study, and the tertiary lagoon will be operated as a winter alternative under the concept of implied improved summer water quality levels.

e. Additional criteria for increased reservoir releases in the winter The release rate from the proposed and authorized Ames Reservoir could be varied seasonally, or even monthly, if higher water quality levels could be achieved in the Skunk River downstream of Ames. As noted previously, any selected average annual release rate, in terms of cfs, is related to drought or low-flow probabilities and should be considered a variant in technical and economic analyses. Because of the apparent need and desirability of low-flow augmentation, it was assumed in this study that the only rational and equitable probability level was that associated with the Iowa stream water quality standards. These specify the 7-day, 10-yr low-flow frequency. Therefore, the capability of the reservoir to deliver 50 to 60 cfs at this frequency or related probability level was used in the case study.

Because the winter period poses a severe problem, an additional alternative provides for increasing the winter peak release rate to 100 cfs. This appeared to be the greatest monthly release rate that could be permitted and yet maintain an annual average of 50 to 60 cfs for the 10-yr frequency level. Such a release scheme, for example, might provide minimum monthly release rates of: January, 90 cfs; February, 100 cfs; March, 80 cfs; April, 50 cfs; May-July, 40 cfs; August-October, 50 cfs, November, 60 cfs; December, 70 cfs; annual average, 60 cfs. For a 50 cfs average annual release rate, these suggested monthly values would need to be reduced by 10 cfs. To reduce the computer runs to a minimum, this alternative was only studied in conjunction with the trickling filter process.

5. Results obtained from the computer study using the Ames water quality model

Thirteen computer runs were made for the 1990 design conditions including 5 for the first category (trickling filter), 5 for the second category (activated sludge), 2 for the third category (tertiary lagoon use in the winter season), and 1 for the fourth (increased reservoir release rate in the winter to supplement trickling filters). The computer output is listed in Appendix H, including the selected input data, tabulated results for DO, BOD, and the other water quality parameters, and plots for the respective runs.

The results of the 13 runs, summarized in Table 117, serve as the basis for discussion and summary remarks. Tabulated values are presented for the DO extremes (maximum and minimum values) for both day and night conditions. The maximum ammonia, phosphate and total BOD_5 concentrations at the outfall after mixing are also listed for comparative purposes.

6. Discussion and summary

The results tabulated in Table 117 provide an excellent opportunity to compare the alternatives selected for analysis. The results also illustrate the major problems confronting water pollution control groups in their efforts to enhance water quality in streams.

a. General results The characteristic DO profiles are obtained for all summer, fall and winter periods, even at the design release rate of 50 cfs from reservoir storage. During the summer and fall periods, daytime DO values are above the 4 mg/1 level for all alternatives. The algal oxygen productivity increases during the season as nutrient

Table 117. Water quality levels for the 1990 design period for selected treatment alternatives, 10-yr frequency level and including low-flow augmentation[a]

Design alternative	Month or season	Daytime minimum DO, mg/l	Daytime maximum DO, mg/l	Daytime DO, end of reach value, mg/l	Nighttime minimum DO, mg/l	Nighttime end of reach value, mg/l	Minimum average daily DO, mg/l	Maximum NH4 level, mg/l	Maximum PO4 level, mg/l	Maximum BOD level, mg/l
Trickling filter	August	7.6	12.5	8.7	3.8	6.0	6.4	1.2	4.9	10.2
	September	8.1	14.3	9.5	1.5	4.0	5.8	2.2	4.9	12.1
	Oct.-Nov.	8.9	14.6	10.4	2.9	4.2	6.4	2.6	4.9	13.2
	Winter, K2ICE = 0.3	11.3[b]	11.4[b]	4.3[c]	4.2	4.2[c]	4.2[c]	3.4	5.0	16.1
	Winter, K2ICE = 0.2	11.3[b]	11.4[b]	2.1[c]	1.9	1.9[c]	2.0[c]	3.4	5.0	16.1
Activated sludge	August	5.9	12.1	8.7	2.9	6.0	4.9	4.0	4.9	11.1
	September	6.9	14.1	9.5	1.1	3.9	4.8	4.0	4.9	11.6
	Oct.-Nov.	8.2	14.5	10.3	2.6	4.1	5.8	4.0	4.9	12.2
	Winter, K2ICE = 0.3	11.0[b]	11.3[b]	4.0[c]	3.9	3.9[c]	4.0[c]	4.2	5.0	14.1
	Winter, K2ICE = 0.2	10.9[b]	11.3[b]	1.72[c]	1.59	1.59[c]	1.66[c]	4.2	5.0	14.1
Activated sludge with tertiary lagoon	Winter, K2ICE = 0.3	11.7[b]	11.8[b]	5.2[c]	4.9	4.9[c]	5.1[c]	2.4	2.9	9.2
	Winter, K2ICE = 0.2	11.7[b]	11.8[b]	3.0[c]	2.7	2.7[c]	2.9[c]	2.4	2.9	9.2
Trickling filter with 100 cfs reservoir release rate	Winter, K2ICE = 0.2	11.8[b]	11.8[b]	3.4[c]	3.1	3.1[c]	3.3[c]	2.0	2.9	10.0

[a]Reservoir release rate of 50 cfs except where noted.

[b]Value occurs in open water before ice cover is reestablished.

[c]Value occurs under ice cover in downstream part of assimilative reach; in some runs the oxygen sag point under ice cover was approached but not reached.

levels increase and also as lower river temperatures provide a higher base level of dissolved oxygen. The BOD levels at the outfall do not vary appreciably during the seasonal sequence, but a greater variation is noted in the trickling filter alternative than for the activated sludge process.

In the summer and fall periods, nighttime DO levels in the assimilative reach are depressed to levels below 4 mg/1. However, the minimum value of 4 mg/1 is reached by the end of the assimilative reach in all instances. It can be seen also that the algal respiration sequence is a critical factor in determining the minimum nighttime DO levels.

Wintertime conditions are also a critical factor in maintaining a desirable DO level in the stream. For the reaeration coefficient value of 0.3 (for K2ICE), the stream DO is above the minimum value of 4 mg/1 (absolute minimum of 3.9 mg/1 for all winter runs). However, the three winter periods for which observations were available indicated observed values less than 2 to 3 mg/1, and a reaeration coefficient of 0.2 was verified for the 1969 winter DO study. Application of the 0.2 value in the water quality model results in DO levels less than 2 mg/1. The computed minimum values were 1.6 to 1.9.

Improvements in water quality can be achieved by introducing the last two improvements listed in Table 117. However, at the minimum reaeration coefficient, the DO levels remain under the standard of 4 mg/1 (2.7 to 3.1 mg/1). Therefore, the water quality levels (for the dissolved oxygen resource) during the winter periods cannot be assured, even with an increased magnitude of low-flow augmentation or with the additional use of a tertiary lagoon.

The results show that in all cases the nutrient levels remain high, and the limiting ammonia standard of 2 mg/l is met only with increased low-flow augmentation. The desirability of relaxing the ammonia standard to 4 mg/l in assimilative reaches (if bioassays show that this concentration is not toxic to fish native to Iowa streams in the central and southern counties) is evident from this analysis. Phosphate levels, even with low-flow augmentation, remain above the approximate non-limiting value of 1.0 mg/l PO_4.

b. Comparative analysis of the various treatment methods The results summarized in Table 117 illustrate the physical tradeoffs that occur in each treatment method, trickling filter and activated sludge. The trickling filter process has higher carbonaceous BOD levels in the effluent but produces lower levels of ammonia. The activated sludge process achieves a polished effluent low in carbonaceous BOD but with higher levels of ammonia. The competitive nature of the tradeoffs in this study resulted in a higher total BOD level in the stream from the activated sludge process. This reflects the results obtained and presented in the chapter on plant effluents. Accordingly, because the effluent DO concentration is also lower, the water quality levels in terms of both DO and ammonia concentrations in the stream are not as desirable as are the trickling filter results.

The trickling filter process in this study produced the higher water quality level in the receiving stream for normal operation of both processes. However, if activated sludge plants are operated specifically for ammonia oxidation (as they frequently are by maintaining higher DO levels during aeration), the results using activated sludge processes can be significantly improved. One alternative would be to use activated sludge units for carbonaceous BOD removal followed by the existing trickling filters for oxidation of the ammonia to nitrate.

Winter conditions can be improved by using tertiary lagoons for temporary storage or increased low-flow augmentation. An increased reservoir release rate of 100 cfs could be provided at little or no additional reservoir cost. This might eliminate the need for the tertiary lagoon. Therefore, there appears to be some merit in conducting additional study of using a variable reservoir release rate.

H. Conclusions

The complex nature of the stream environment and its associated response to effluent discharge has been expressed in mathematical terms. The mathematical model for dissolved oxygen and related organic loads developed in this chapter permits the prediction of the assimilation of organic carbonaceous and nitrogenous BOD loads discharged to the stream, includes the effect of atmospheric reaeration as limited by winter ice cover periods, provides for the boundary BOD contributions that cause the stream to have a base level of BOD, and accounts for the observed increase in algal oxygen productivity in the daytime and the algal respiration liability at night. The mathematical models for dissolved oxygen and for assimilation or decay of other potential pollutants and water quality parameters have been incorporated into a comprehensive digital computer simulation model labeled as the ISU water quality model. The development of this model has been documented in the text and complete details concerning it included in the appendices.

The water quality simulation model was tested in a verification study phase and improved in stages until it could simulate the levels of water quality in the Skunk River observed in field water quality studies. Adequate simulation of the observed results was obtained, and the prediction capability of the model is considered to be satisfactory. The complexity of the model is indicated by the input requirement of 56 factors or values. As with most models of this type, its use is limited to situations in which observed conditions can be reproduced or verified. Then, within limits, it can be used as a forecasting tool.

The ability of the model to forecast water quality levels was tested first using the 1970 status of water quality levels in the Skunk River, at and downstream of Ames. The results of this analysis, for the sequence of summer, fall and winter seasons also appeared reasonable and realistic in nature. The stream is stressed heavily by the effluent load from the existing overloaded waste treatment plant. At low-flow discharges of 10-yr frequency, for which state standards would normally apply, the DO levels are below the minimum (4 mg/l) and ammonia levels are above the maximum permissible value (2 mg/l). In addition, the increases in temperature of the stream are greater than listed in the Iowa standards, especially in the winter period.

The last phase of the technical studies included forecasting stream behavior under selected 1990 conditions. Low-flow augmentation formed a basic part of this analysis. Although water quality in the stream can be enhanced through low-flow augmentation and increased treatment efficiencies, it remains difficult to obtain ideal levels of water quality. Both trickling filter and activated sludge secondary treatment processes were included in the 1990 forecasting study. Two winter alternatives were included in an effort to achieve higher levels of water quality when ice cover poses a problem.

Three major influences can be identified in the summary tables for the verification study, the 1970 status study, and the 1990 forecasting study (Tables 112, 114, 116 and 117). The results obtained with the Ames water quality model may not provide absolutely accurate answers, but the results are reasonable and can be used to advantage in comparing alternatives and in exploring the potential for improving the waste treatment process. The nighttime algal respiration as computed may be somewhat more severe than the observed relationships in depressing the nighttime DO levels. This can be checked by comparing the minimum DO values and related BOD levels in Fig. 72 with the minimum DO and BOD values listed in Table 117. Both the observed data and the prediction results listed in Table 117 indicate that the BOD_5 loading in the stream must be limited to about 10 mg/l, after mixing, if the Iowa standard of 4 mg/l of DO is to be maintained in the assimilative reach. This is a relatively low value of BOD_5 and implies that good dilution water must be available or low-flow augmentation considered as a supplementary measure. If the BOD_5 loading is increased to 20 mg/l, the DO level is depressed to 3 mg/l or less, as indicated in Fig. 72, and evident also in the results listed in Tables 116 and 117.

A comparison can now be made between the results listed in Table 117 (for BOD_5 and related DO levels in the Skunk River basin) and those listed in Table 18 which were based on regional considerations. Additional regional implications can be derived from these relationships. For the Region III analysis made in Table 18, the maximum permissible L_a values were 8.2 mg/l (f = 2.0) or 13.5 mg/l (f = 4.0) for the summer conditions. This regional evaluation was made using the relationships derived with the simple Streeter-Phelps mathematical model for dissolved oxygen deficits. The stream temperature for the two separate studies was the same, 90 deg F. The L_a values in Table 18 can be converted to BOD_5 values using the GAMMA1 factor. If a value of 0.80 is applied, then the regional BOD_5 values are 6.6 and 10.8 mg/l. The Skunk River water quality studies produced river values of f equal to 2.5 to 5.0 (K_1, 0.8 to 2.0; K_2, 4.0 to 5.0). These values indicate that the regional estimates using the higher f values are the more realistic.

It appears evident that the nighttime DO results or the mean daily DO levels obtained with the ISU water quality model, as associated with the BOD_5 concentration in the stream at the outfall, correlates somewhat with the general results obtained with the Streeter-Phelps model for regional analysis. A limiting value of about 10 mg/l of BOD_5 is obtained from this comparison for achieving a minimum of 4 mg/l DO in the streams in Region III. Extension of this conclusion would result in limiting BOD_5 concentrations of 12.5 mg/l for Region II and 15 mg/l for Region I for the assumed summer conditions. However, if accurate determination of the daytime-nighttime DO relationships are desired, the ISU water quality model offers the best opportunity for obtaining these results, and would be preferred over the Streeter-Phelps model.

Therefore, the regional estimates made in Chapter V have received additional confirmation. These estimates may be suggested for use in obtaining an initial approximation of the limits which should be considered for effluents so that the minimum desired DO level can be maintained in the stream. The dilution ratios, low-flow requirements, and population loadings per unit of streamflow or drainage area which were listed in the regional analysis (Tables 19 and 20) become additional tools which can be used in regional planning programs and in laying the groundwork for additional field studies and establishment of data collection networks in the state of Iowa.

The conformity of the simulated or predicted results with the observed water quality levels indicates that the Ames water quality model provides much more accurate results than would be obtained with less complex mathematical models or with the more complex models reviewed previously but which failed to include the increased algal oxygen productivity observed in the Skunk River (and which probably occurs in many other Iowa streams in Region III). The model does provide an opportunity to forecast water quality levels under varying circumstances and can be used also to test the sensitivity of many factors that influence stream water quality.

The three major influences of effluents on stream water quality that have been identified in this study can now be summarized. These are:

(1) The effluent carbonaceous BOD load,

(2) The ammonia nitrification problem, or nitrogenous BOD loads,

(3) The algal growth problem and related oxygen productivity due to nutrient loads, and the associated respiration phase at night.

The results listed in the summary tables (Tables 112, 113, 114, 116, and 117) show that additional BOD reductions for the 1990 design level, from increased treatment efficiencies, cannot be expected, nor would they be realistic. If water quality is to be enhanced above the levels indicated in Table 117, it can be accomplished only by attacking the two remaining problems. These are the ammonia nitrification problem and the algal growth phenomena associated with high nutrient loads. Low-flow augmentation is only a partial solution to the overall problem of enhancing water quality in the Skunk River.

In addition to consideration of the beneficial effects of low-flow augmentation, the city of Ames should consider other possibilities for reducing the carbonaceous BOD, the nitrogenous BOD and the nutrient levels (primarily the phosphates). Carbonaceous BOD removals beyond 95% using activated sludge processes or beyond 85% to 90% using trickling filters is <u>not</u> economically feasible. Increased carbonaceous BOD removal can be obtained by rapid sand or diatomite filtration of the plant effluent.

Increased nitrogenous BOD removals cannot be expected using trickling filters; but, revision of operating conditions of activated sludge plants can be expected to provide a more highly nitrified effluent than was assumed in this study. In general, however, ammonia concentrations appear to be a significant problem. Technically, there is question as to whether the nitrogen should be removed from the liquid as ammonia (by stripping) or converted to nitrate and allowed to discharge to the stream (as from the storage lagoon used in this study).

Phosphate removal for control of the algal activity (detrimental respiration at night) can only be accomplished by lime or alum precipitation. Studies using the ISU water quality model can be used to evaluate the effectiveness of each method of treatment on its potential enhancement of stream water quality.

XIV. ECONOMICS OF WATER QUALITY MANAGEMENT AT AMES, IOWA

A. Basic Relationships Existing Between the Physical and Economic Dimensions

The technical studies of the stream water quality environment and of its response to effluents discharged from water pollution control plants have resulted in the development of several important input-output water quality relationships. The ISU water quality simulation model (a mathematical model) incorporates these input-output responses and permits forecasting water quality levels in the stream for a variety of conditions. The ability to determine the response of the stream to waste inputs provides the physical coefficients and determinants necessary for economic analysis. Numerous economic relationships can now be explored. The scope of this initial stream water quality research effort does not permit study of extensive economic analyses; therefore, this remaining phase of the three water quality dimensions studied (technical, structural, and economic) will be presented in a simplified approach.

The nature of the economic problem as it relates to stream water quality in the Skunk River basin is discussed first. The neutral, complimentary, and competitive relationships of water quality economics are explored. Then, the economics of water pollution control at the city of Ames are evaluated in the last two sections of this chapter. Two types of economic analyses were conducted in the evaluation of the cost of water pollution control. The first was an evaluation of the cost of water pollution control (and related stream water quality management) at Ames under existing conditions. The cost of water pollution control was then compared with other municipal expenditures. This provided a simple but adequate means of measuring the local contribution which each resident makes to this one (but important) environmental problem, and the competition which may exist in the future as an improved or enhanced status of stream water quality is desired (or required by state of federal edicts).

The second study consisted of an economic evaluation of the cost of water pollution control and stream water quality management at Ames under future conditions of population stress and associated waste loads. The results of the several physical or technical alternatives which were studied and summarized in the previous chapters formed the basis of this evaluation. These alternatives included: (1) continued use of trickling filters to meet the secondary treatment requirement; (2) introduction of the activated sludge process (assuming a measure of nutrient control); (3) additional use of a tertiary lagoon; and (4) use of the low-flow augmentation alternative offered through the proposed Ames Reservoir.

B. The Scope of the Economic Study

1. Review of the technical study results

The results obtained in the field water quality studies and in using the mathematical model have shown that the assimilation of effluents is rapid. In the summer and fall seasons, the stream (the Skunk River) recovers to a satisfactory level of water quality (i.e., meets established state standards) before the next downstream community is reached. This was evident from observations of (1) community septic tank outflow at Blairsburg, with Ellsworth being the downstream community, (2) the raw sewage discharged at Ellsworth (1965-67), with Randall and Story City being the downstream communities, (3) effluent discharged from the Story City water pollution control plant (trickling filter units), with the Ames urban area being the downstream community, and (4) the effluent discharged from the Ames plant, with Cambridge and Colfax being the downstream communities. The Colfax plant, in turn, influences the stream environment in the reach between that community and Oskaloosa.

These several communities, however, discharge substantial amounts of nutrients (nitrates and phosphates primarily) to the stream environment. The stream, from visual evidence, is fairly heavily laden with algae in the late summer and fall low-flow periods. A definite green color persists in the deeper pools and only in the shallow riffles does a semblance of clear water exist. Despite the nutrient load, the DO and other water quality levels are reasonably satisfactory at the downstream end of each assimilative reach. To illustrate the distances involved, the communities having municipal waste collection systems (and the respective distances between them) are summarized in Table 118. The list of communities located on the Skunk River does not include the town of Cambridge, located about 9 mi downstream of Ames. Cambridge is located on a sandy terrace above the Skunk River valley. Although the town has a municipal water system, there is no municipal sewer system or waste treatment facility. Apparently the sandy soil has been capable

Table 118. Spatial location of designated assimilative reaches in the upper Skunk River basin[a]

Municipality or community	Mileage from Mississippi River	Length of available assimilative reach between communities, miles
1. Blairsburg	275	
		20
2. Ellsworth	255	
		24
3. Story City	231	
		18
4. Ames	213	
		31
5. Colfax	182	
		14
6. Reasnor	168	
		30
7. Oskaloosa	138	

[a]Stream mileage data listed previously in Table 25.

of absorbing and percolating the effluent from individual septic tank systems. The community is not listed in the reports of the implementation plan of the Iowa Water Pollution Control Commission (1967, 1968). Therefore, the nearest downstream community that is currently competing for the stream's assimilative capacity is Colfax, located about 30 mi downstream of Ames. As shown previously, the assimilative reach under summer conditions for the Ames effluent (and the related algal growth problem) is in the upstream one-third to one-half of this 30-mi reach.

2. Lack of interdependence in the use of the stream system

The results of the water quality research study indicate that each community's use of the stream for effluent disposal is largely independent of any other community's use of the stream for the same purpose. There is no real competition for the assimilative capacity of the stream for purposes of water pollution control. Although winter season conditions may vary somewhat from the observed and computed summer conditions, there appears to be no real competition among the communities (in the winter) since no reports of fish kills, etc. are known to have been recorded. The low amount of use of the stream for recreation in the winter also favors excluding this season in this initial analysis, and any specific winter problems that might exist will be assumed away in this study.

Several important implications can be derived from these relationships. The lack of competition in the physical sense has an important bearing in extending the economic analysis to a regional scope. There is no real need to incorporate multiple sources of waste effluents into a more extensive analysis, as illustrated with Eqs. 78 and 79, at least in this initial study. In addition, the competitive role indicated with the linear programming models of Eqs. 88 and 89 finds little application in this initial case study of stream water quality in central Iowa. Therefore, economic analysis must be limited to the effect of individual community use of the stream system on the beneficial uses made of the stream and the water within. The relationship of water quality control (as evidenced by individual community use) to other beneficial uses of water in the Skunk River is the next step in this study.

C. Benefits of Water Quality Enhancement in the Skunk River Study Reach

1. Identifying beneficial uses and related aspects

The economic relationships that can be applied to water quality enhancement programs in the Skunk River basin study area depend on the existing or potential beneficial uses that compete for the water. These uses were identified in the introductory chapter as: (1) water supply for domestic, municipal, industrial or agricultural purposes, (2) power production, (3) navigation, (4) recreation, (5) fish and wildlife propagation, and (6) water quality control associated with effluent disposal.

Water supply is a limited use in the study reach of the Skunk River. Upstream of Ames the valley is narrow with considerable pasture land along the river and adjacent bluffs. Livestock use the stream as a source of water supply. Downstream of Ames, the few pastures encountered along the main stream have shallow wells as the primary source of livestock water supply. Some irrigation has been practiced both upstream and downstream of Ames, using the Skunk River as a surface water supply (Iowa Natural Resources Council, 1957). However, in recent years the crop-season and annual precipitation have been sufficient to raise normal crops and for seed corn production which is heavy in the Ames area (a spin-off benefit of the University's research program). The irrigation use of water has remained dormant during the field studies. The auxiliary water supply intake at Oskaloosa also represents an intermittent use aspect, with the additional potential and advantage of shallow wells in the alluvium further discounting the use of surface waters in a physical and an economic sense. Navigation in this non-meandered stream is limited to that associated with recreation. Power production (including cooling) has little real potential under the existing conditions of variability and distribution of the low-flow discharge of the stream. Although some of these uses will grow in potential and actuality if the Ames Reservoir is constructed and achieves a measurable amount of flow augmentation, such potential for industrial and agricultural-irrigation use of the water may be limited by the structural dimension (Peterson, 1966). This potential needs to be evaluated, however, both for existing and for proposed federal reservoirs in Iowa, but is beyond the scope of this water quality study.

Therefore, the competition of beneficial uses in the study reach of the Skunk River is limited to three: water quality control, recreation, and support of fish and wildlife. However, there are no designated or recognized public recreation areas along the stream between Ames and Colfax. The recognized recreation and related fish and wildlife access areas are all located in the upstream reach between Story City and Ames. The one public recreation area located in the Skunk River valley in Polk County is actually on the old stream meander pattern (that existed prior to channel straightening) and old oxbows, away from the present channel. The only access points for recreation and related fishing, hunting, and related to other secondary contact sports are at the bridge sites where the public road rights-of-way cross the stream. Elsewhere the recreation enthusiast must actually trespass on private property to use the stream environment.

This situation makes it difficult to determine or assign real benefits for recreation use of the stream system. The primary achievement of improved or enhanced water quality in the stream is therefore limited to riparian use or enjoyment and the limited bridge access to recreation opportunity. These might be lumped into the "esthetic" category for all practical purposes. There is some trapping along the stream in early winter for fur-bearing animals, the one wildlife aspect having a beneficial use aspect. Otherwise, wildlife propagation is directed towards the sport of hunting within the confines of the state permit regulations after obtaining the permission of landowners to hunt on private property. In the absence of gross pollution, it is difficult if not impossible to evaluate or measure the value of enhanced water quality on these recreation, fish and wildlife uses. Therefore, the esthetic aspect is the only remaining reason to achieve higher levels of water quality associated with the use of the stream.

2. Cause and effect relationships existing between the beneficial uses of water

The three types of relationships that may exist between or among water uses have been identified using a cause-and-effect concept (Timmons, 1967; Timmons and Dougal, 1968). These three fundamental relationships are: (1) neutral, (2) complementary, and (3) competitive. The relationship of quantity and quality uses in the Skunk River study reach will be reviewed within this framework.

a. Neutral relationships Neutral relationships exist between uses of water when use has no effect of the water quality required of other uses. Each use is neutral to the other use or uses and no decisions regarding water quality need be made prior to proceeding with or continuing both or all uses. This appears to be the status of the communities using the stream system of the Skunk River for effluent disposal. Each community's use is independent of all others. This neutral relationship may, however, collapse during the winter season if the cold temperatures and ice cover cause the depletion of dissolved oxygen (DO) to sweep downstream, and if in addition the ammonia present (and its toxicity) oxidizes much more slowly and carries downstream to interfere with other uses.

The water quality in the stream may also have a neutral relationship with recreation uses in the winter season, if the primary recreation use is associated with the ice surface (skating, sledding, hiking, hunting, etc.). Presumably a neutral relationship would exist also between stream water quality (influenced by effluent disposal) and agricultural crop irrigation use (from stream withdrawals). Since the assimilative process results in an improvement in quality levels associated with nonconservative substances, the downstream water quality would be of greater value than the effluent quality at the outfall. However, the ammonia levels at the outfall (a source of fertilizer) might be preferred at the downstream withdrawal point. The complimentary nature of some of these relationships will be explained below.

Although no use is currently being made of the stream water for power production, this use if added also should present a neutral relationship with stream use for municipal water quality control. The temperature environment between these two uses might vary, however, depending on whether the power use was in a hydroelectric system or in direct cooling water for a steam electric plant. Although quantity aspects might be neutral, the quality use associated with temperature might not be. The competitive nature of this conflict will be explained below.

Because the auxiliary water supply intake of the city of Oskaloosa is downstream of the summer season assimilative reaches, a neutral relationship exists also between the stream use for water supply and for effluent disposal. However, this might be tempered somewhat by the comparative levels of suspended algae (planktonic forms) which could easily affect the treatment required to produce a drinking water. The ease with which groundwater wells can be installed in the alluvial valley (Twenter and Coble, 1965) may also discount the importance of using the Skunk River as a source for surface water supplies for communities, and encourage the development and continuance of a neutral relationship between these two uses of the stream system.

b. Complementary relationships A complementary relationship develops between beneficial uses when one use upgrades or improves the quantity or quality of the water for a second use, without the converse occurring. This relationship exists to a considerable degree in the reach of the Skunk River downstream of the city of Ames. The effluent that is discharged at the water pollution control plant adds measurably to the low flow of the stream. As noted several times in previous chapters, the stream is frequently dry upstream of the outfall. Therefore, the effluent discharge is a physical contribution to streamflow. and for quantity aspects a complementary relationship exists. In addition, if the high ammonia or nitrate levels are desirable in an irrigation water, then the quality aspect is also complementary. Some irrigation has been practiced in the Skunk River valley in the reach downstream of Ames, but the lack of severe drought conditions in recent years has caused this use to remain dormant. The complementary nature of effluent disposal to low-flow augmentation for general riparian use and for additional beneficial recreation, fish and wildlife use downstream of the assimilative reach was also mentioned previously. The difficulty of evaluating the worth of the effluent discharge in these special temporal or spatial situations is apparent.

The additions to low flow also indicate some economic inequity to communities. If an irrigator withdraws the augmented flow for agricultural use under the structural relationships existing in Iowa, there is no specific charge made for the water (which has been declared to belong to the public). He cannot, however, dry up the stream because of the protected low flow established in the Iowa water permit statutes (Iowa Natural Resources Council, 1964; Peterson, 1966). Nevertheless, the city has no statutory economic protection permitting it to collect, sell, or otherwise obtain some remuneration for the water addition it makes to the stream. This could be termed an "unrecovered complementary use" aspect of the economics of water and its related quality as pertaining to municipal effluents in Region III where effluent discharge provides some water to the streams during drought periods (especially if the source of supply is a deep aquifer). The economic value of the quantity addition cannot be recovered, whether it serves as flow augmentation for general public esthetics or for riparian use.

c. <u>Competitive relationships</u> The competitive relationships between water uses, both in a quantity and quality sense, arise when one use definitely conflicts with one or more other uses; or they arise when conflict occurs between users for the same beneficial use. As noted by Timmons (1967), these competitive relationships between water quality uses are the core of water quality control problems. As indicated above, there is a somewhat unique lack of competition between or among communities for waste assimilative purposes as long as the assimilative reach for each extends no farther downstream than the next community. In metropolitan areas where several communities are located closely along the streams or rivers, then a competitive situation can exist and allocation of the waste assimilative capacity can be evaluated in economic terms. These evaluations where made have usually favored metropolitan collection and central treatment facilities, or the highest degree of treatment at major sources of pollution where economies of scale could be achieved. This situation may arise at Ames, and the suburban areas surrounding the city, if the rapid growth of the community occurs in outlying areas to which major interceptor sewers have not yet been extended. It is not likely that interceptor sewers would be constructed into such areas for some years. The installation of "package" waste treatment facilities at these small but concentrated sources of pollution cause a semblance of a metropolitan waste disposal problem at Ames.

Greater competition exists among the several beneficial uses which can be made of the Skunk River system at Ames. However, competition in theory does not necessarily mean competition is actuality since the magnitude of the conflict may be so small as to be immeasurable, at least in economic terms. To describe the competitive nature of water quality problems, a fourfold economic classification has been proposed (Timmons and Dougal, 1968). The four relationships were entitled: (1) the encroaching relationship, (2) the spatial-preclusion relationship, (3)the temporal-preclusion relationship, and (4) the compensatory-continuance relationship. Application and explanation of these concepts as they describe the water quality environment at Ames illustrate the four relationships.

The encroaching relationship applies to existing situations in which the receiving water is polluted to some degree by the effluent discharge. The effect of lower water quality levels upon one or more other beneficial uses is either increased costs or reduced benefits (lower net value of output). However, all uses remain in the economic market place, with their profits remaining above the "break-even point." All of the beneficial uses can continue to function, and no water quality control measures are required (of the institutional dimension).

In the Skunk River case study at Ames, the discharge of effluent during low-flow periods alters the water quality level of the stream. A downstream irrigator might find that the quantity aspect and the ammonia concentrations to be highly complementary, but the organic loading results in a slime growth in his sprinkler system which clogs the sprinkler heads, etc. However, the increased cost of cleaning, lower application efficiency, etc., do not offset the economic gains involved in using the "slightly polluted" water. Another example would apply to the recreation, fish, and wildlife uses of the stream. Ammonia levels may increase to the point where the species of fish change to those tolerant of the higher ammonia levels (carp, buffalo, etc.). Sport fishing at bridge sites may continue, but the fisherman is not as elated with his catch, and the "intangible" value of his recreation experience is not as great.

As pollution levels increase, the danger to health (in the absence of effluent chlorination) may also increase. The problems of water borne diseases, especially infectious hepatitis, may need to be considered. The location and growth of residential developments south of the Ames water pollution control plant along the bluff of the valley encourage the use of the stream by the youth of the area. Body contact and potential ingestion of water become real problems. Thus, each of these growth events (residential development and increases in waste load) is an encroaching relationship upon the other. The cost of disinfecting the effluent represents the economic interplay between the encroaching relationships.

The encroaching relationship effect upon water supply is considered to be minor, since the only water supply intake is at Oskaloosa. Although greater pollution loads in the future may result in extension of the assimilative reach in the downstream direction, the field observations and the mathematical model results indicate that dilution or dispersion to safe levels will be achieved. The encroaching relationship on one additional agricultural use should be considered. A few pastures are located along the stream between Ames and Cambridge, with only one additional pasture observed between Cambridge and Colfax that is actually adjacent to the river. Reduced water quality levels due to effluent discharge can affect the use of water for livestock purposes (FWPCA, 1968). However, the banks of the river are steep, over 8 to 10 ft in height, and field inspection discloses that shallow wells and windmills supply water to the livestock. Therefore, although implied by the existence of the pastures, it does not appear that a direct encroaching relationship exists.

A spatial-preclusion relationship develops if one or more existing downstream users of water is precluded from making beneficial use of the stream water as quality levels are lowered more and more by the discharge of effluents at an upstream point. The upstream use has now foreclosed entirely the spatially-located downstream use (or uses). The downstream use that is precluded from continuing may have had a higher (or equal) net return or benefit than the upstream use, but the additional on-site costs of removing or remedying the water pollutants are completely prohibitive to the downstream use. In the absence of control measures of the structural dimension (water quality stream standards, for example), the precluded use disappears physically from the scene although economically it would benefit society if a more optimum solution were available.

An example of the spatial-preclusion relationship operating in the water quality environment was evident in the case of untreated wastes discharged to the Skunk River at Ellsworth. In this upstream area, the valley is narrow and both it and the bluffs are in pasture. Purportedly, a downstream dairy farmer now faced two possibilities as gross pollution of the stream occurred. Either he could fence the stream and separate the stream environment from the pasture use, or he would be precluded healthwise from maintaining a Grade A dairy operation. Whether actual or potential, the case illustrates the spatial preclusion arising from continued pollution of the stream.

Gross pollution of streams can cause the spatial preclusion of recreation uses very rapidly, especially for the esthetic use in secondary recreation activities. When primary effluent was discharged to the stream at low-flow levels, the resulting degradation of the aquatic environment was not esthetically appealing nor was it beneficial to the fish habitat. In the vicinity of the outfall a few fish failed to survive. Fish swimming downstream were observed to turn around and swim upstream to avoid the outfall point. Presumably, this level of pollution would spatially preclude most of the recognized beneficial uses in this reach of the stream. Because the stream recovered before reaching the Colfax area during such periods of high stress, the spatial preclusion would apply only to this reach. The use of the stream for water supply at the Oskaloosa auxiliary intake is not, therefore, spatially precluded.

The <u>temporal-preclusion</u> relationship represents a future, temporal type. A downstream water use (existing or potential) has a need for the stream water in the future, but is not presently using it. However, continued use of the stream for effluent disposal by one or more upstream uses reduces the level of water quality progressively to the point where it economically precludes the potential downstream use from ever making beneficial use of the water. The potential beneficial use may need the water to meet new demands at an existing or new location (such as agricultural irrigation use), but would be required to incur incremental costs in excess of the net value or net return for the output attributed to the new water supply. A variation would be a potential new use that would be economically profitable only by accomplishing offsite treatment at the effluent discharge point, with it being physically or economically impossible to improve the water quality to the desired level at the potential intake point of the downstream user.

This temporal-preclusion relationship might arise in the study reach of the Skunk River if the effect of pollution, from the city of Ames, progressively reached farther downstream and eventually affected the auxiliary water supply intake at Oskaloosa. If this community prospered at some time in the future and desired to make continuous use of streamflow under the temporal preclusion category, it would now find that it could not do so. The same situation, at Oskaloosa, might occur if an expansion of the sand and gravel extraction operation at Colfax resulted in continued high turbidity in the stream water. However, these two potential effects are largely hypothetical; the alluvial sand and gravel deposits serve as an ideal aquifer for beneficial use throughout the length of the stream from Ames to the boundary of Mahaska and Keokuk Counties, and water permit regulations, if enforced, should prevent the latter situation from occurring. Industrial uses also prefer the groundwater source because of the more constant temperature, low turbidity, etc. which give it a decided economic advantage. Increased pollution would have the greatest effect on the potential use of the stream system for recreation. Because the reach from Ames to Oskaloosa is a dredged channel, no great appeal for recreation development is foreseen.

The last competitive relationship to be discussed is the compensatory-continuance relationship. This derives from voluntary or regulatory control measures which exert an influence on the competitive use of the stream system. This relationship provides an opportunity to distribute the offsite costs of stream pollution in conformance with the economic factors discussed by Kneese (1962, 1964).

Frequently a downstream water use is affected adversely by upstream waste discharges. The treatment choice faced by the downstream use is to (1) remove certain residual pollutants at the upstream point of discharge, (2) remove them at the point of downstream use, or (3) develop another source of water. The costs of the latter two choices frequently may be prohibitive. This would be especially true for a constituent in dilute quantities. It may be that the minimum net social cost would be achieved if the upstream waste discharger removed the residual pollutants as part of the processing cost (since treatment would be more effective and at reduced costs with the higher concentrations existing prior to discharge and dilution). Under this relationship, the downstream use might be induced to pay a portion or all of the water quality improvement costs as an alternative to preclusion or to higher treatment costs. A compensatory-continuance relationship might also be achieved through the structural dimension (state or federal control measures), compensation being achieved between the parties by a system of assessments, penalties, taxes, or some other mechanism.

If the assessments or penalties are large, another form of the compensatory-continuance relationship can apply. In this case, the upstream discharger of effluents would be induced to furnish the downstream use with an alternative source of water in the form of wells, surface impoundments, or other alternatives. This alternative-source concept appears to have substantial merit in the case of municipal use of the stream system for disposal of effluents (which have received secondary treatment) when this use is in competition with stream use for recreation, fish and wildlife.

This latter situation has the greatest application role in the case study of the Skunk River at Ames, Iowa. There appears to be no great conflict of municipal water pollution control with the other beneficial uses of water. The primary influence of a competitive nature exists in the effect of the effluent discharge on recreation, fish and wildlife uses. Because of the nature of the channel characteristics, recreation use is primarily of the secondary contact category. Esthetics is involved in this category, or "water that is pretty to look at" (Wendell, 1966). This is especially true in the reach of stream between Ames and Colfax on the main channel. Enhancement of water quality through improved secondary treatment practices or tertiary treatment additions would only create "prettier water to look at."

If the city of Ames had to meet the established stream standards for recreation and aquatic life, some form of tertiary treatment would in all probability be required. Under the compensatory-continuance relationship, the city could evaluate the alternative of providing an off-stream impoundment for recreation use. This might be constructed and operated at a cost much less than the cost of tertiary treatment. During low-flow periods, the width of the Skunk River is about 50 ft, and in the 30-mi reach between Ames and Colfax the total water surface area is about 180 acres. If the cost of providing an off-stream impoundment (or several smaller ones) of 180-200 acres in total area were less than the cost of additional waste treatment, it might be a desirable alternative. Because of the stability of water levels, control of access and use, and other attributes associated with artificial lakes for recreation, an enhancement of recreation might be a "spin-off" benefit. The bluffs along the valley are sufficiently high to permit constructing impoundments so that this alternative is technically feasible. Therefore, it becomes an economic alternative worthy of study if the need arises (because of regulatory requirements).

Under the compensatory-continuance relationship and its related compensation schedules, satisfactory levels of water quality are obtained for the respective beneficial uses of water at a lower net social cost (or minimum reduction of net social benefits). The compensatory-continuance relationship may be of substantial importance in evaluating regional water quality control programs and in the application of effluent charges, penalties, etc. as increased effort is made to "enhance" the water quality in Iowa streams.

3. Summary

The status of existing or potential beneficial uses indicates the limited nature of the benefits to be derived from enhancing the stream water quality in the study reach below Ames. The use of the stream system is competitive as between its use for effluent disposal and as an esthetic background value in recreation.

This reduces the problem of economic evaluation to a minimum cost strategy, and efforts must be directed towards achieving the required (or desired) levels of water quality at minimum cost to the community of Ames. The established stream standards (DO, ammonia, coliform counts, etc.) become constraints in this analysis unless they are relaxed at least for the purpose of determining the sensitivity of treatment costs with incremental changes in the levels of water quality that might be permitted. The remainder of this chapter will be devoted to an economic analysis of water quality at Ames.

D. The Cost of Water Quality Management at Ames, Iowa

1. Introductory concepts

One of the abiding principles of modern water resources planning and development is closure of the loop between resource use and disposal of the residues associated with that use (U.S. Senate, 1960j; National Academy of Sciences, 1966a, 1966b). Therefore, the cost of treating the waste water of a community can be assessed back to the residents to reflect the total cost of obtaining a water supply, using it, and disposing of it. The cost of water pollution control (in a management sense) at Ames as it affects the lives and economic values of its residents is discussed in this section. By placing the costs of water quality management on a per capita or per resident basis (or related PE, or population equivalent basis), one can obtain an estimate of the comparative value placed on this expenditure in relation to other municipal expenditures. Of particular value will be the comparison between water supply and water pollution control. This method of analysis appears extremely valuable in the sense that decisions (as well as the costs of enhancing water quality in the streams) will be a matter affecting (1) the voter, (2) the consumer, and (3) the taxpayer. Since these three are actually one individual, a city resident, then economic evaluation of water quality management provides in this sense a more personal and meaningful value from which decisions might be formulated.

2. The annual costs of selected municipal enterprises at Ames

Data for the economic analysis of water supply, waste water treatment, and other expenditures within the community were obtained from both the city and the university. The categories selected for analysis included those listed by the city of Ames for municipal services with income received from both revenue and tax sources. These were (1) General — basic city administration, (2) Municipal enterprises — library, airport, and cemetery, (3) Public safety — fire and police, (4) Recreation — parks, playgrounds, and miscellaneous, (5) Sanitation — sanitary land fill, storm sewer, and miscellaneous, (6) Street — maintenance and construction, (7) Utilities — electric, water, and waste water, (8) Miscellaneous —

parking and other.

The following services are provided by "private" utilities under franchises granted by the city: telephone, natural gas, and garbage collection ($3.00 per month per residential home in 1969). The university also has a physical plant and provides water, electric power, and heat to university buildings and certain student housing facilities. Dormitories are served either from the university or the city water distribution system. All waste water in the community (except for outlying suburban areas) is treated at the Ames water pollution control plant. Additional local services which are provided through the county, state and federal governments, including elementary and secondary education, social welfare, etc., will not be considered in this study. The city of Ames uses a sewer rental charge based on water use; therefore, the water user is paying also for treating his waste water. The National Animal Disease Laboratory and Iowa State University are billed by the city for treatment of their waste water. The NADL charge is based on three factors: flow volume, BOD, and suspended solids; the university contributes financially on the basis of flow volume only.

Municipal expenditures were adjusted to reflect comparative university expenditures for equivalent items. Some difficulty was encountered in separating certain annual capital expenditures that should be amortized and included in bond retirement or its equivalent, bond reserves. The adjusted and corrected data are presented in Table 119. The total adjusted city expenditures may be less than presented in the present city budget, but reflect some adjustment for capital expenditures

Table 119. Selected municipal utility expenditures for the city of Ames, 1955-1967, expressed in terms of total costs and per capita (PE) costs[a]

Year	Population equivalent, PE	Water supply[b]		Water quality management		Other sanitation measures[c]		Total annual community expenditures[d]	
		Total	Per capita (PE)	Total	Per capita (PE)	Total	Per capita (PE)	Total	Per capita (PE)
1955	25,000	$373,000	$14.92	$ 62,800	$2.51	$ 75,500	$3.02	$2,640,000	$105.60
1956	25,400	382,000	15.04	65,500	2.58	95,500	3.76	2,950,000	116.10
1957	25,800	406,000	15.74	72,200	2.80	109,300	4.24	3,380,000	130.20
1958	26,200	403,000	15.38	77,100	2.94	111,000	4.24	3,420,000	130.50
1959	26,600	428,000	16.05	114,000	4.28	104,000	3.91	5,830,000	219.20
1960	27,000	471,000	17.44	126,000	4.67	143,000	5.30	6,510,000	241.10

[a]Data obtained from annual budget reports (City of Ames, 1968) and annual financial reports of Iowa State University (1968).

[b]Annual operating costs and amortization of capital expenditures and adjusted to include estimated university water costs.

[c]Includes sanitary landfill, animal control, health inspections, licenses, etc. but excludes hospital costs.

[d]Annual actual expenditures, adjusted to include comparable light, power and water functions of the university, with additional adjustments to amortize out certain capital expenditures appearing in annual budgets.

Table 119. Cont.

Year	Population equivalent, PE	Water supply[b] Total	Water supply[b] Per capita (PE)	Water quality management Total	Water quality management Per capita (PE)	Other sanitation measures[c] Total	Other sanitation measures[c] Per capita (PE)	Total annual community expenditures[d] Total	Total annual community expenditures[d] Per capita (PE)
1961	29,000	$412,000	$14.22	$169,000	$5.83	$149,000	$5.14	$5,360,000	$184.80
1962	31,000	458,000	14.77	161,000	5.19	146,000	4.71	6,390,000	206.10
1963	33,000	524,000	15.88	165,000	5.00	151,000	4.58	6,460,000	195.80
1964	35,000	487,000	13.93	156,000	4.46	129,000	3.69	6,540,000	186.90
1965	37,000	526,000	14.22	175,000	4.73	164,000	4.43	7,400,000	200.00
1966	40,000	560,000	14.00	186,000	4.65	134,000	3.35	8,600,000	230.00
1967	43,000	610,000	14.16	176,000	4.10	175,000	4.07	9,800,000	228.00

which have been substantial at the municipal electric utility. These values are not intended to be precise because of the difficulties noted, but they are listed in a consistent manner to provide a basis for comparative analysis and discussion. Therefore, the expenditures listed represent a minimum level, and more precise evaluation might result in greater values.

The results tabulated in Table 119 include both total expenditures and per capita costs. The consistent upward trend in total costs through the study period is due not only to the population growth (expressed here in terms of PE), but also because of the general inflationary trend during the period. However, per capita costs have not increased measurably. This indicates some economies of scale in operating city utilities, as increased efficiency is achieved.

The per capita (PE basis) annual expenditure data were averaged for the period 1960-1968 (9 yr). The average annual costs obtained were: about $15 per capita for water supply; $5 for water quality management (pollution control); approximately $4.50 for other sanitation measures; and about $210 for all municipal services. This indicates that a total of $20 per capita is spent annually for water supply and waste water disposal, with the latter cost being about one-fourth of the total. Or in other terms, a city resident spends 3 times more for his water supply than he does for its disposal. Because the sanitation category includes the cost of operating the municipal land fill, a rough estimate can be made of the cost of solid waste disposal. To the $4.50 cost figure must be added the cost of private garbage and trash collection. If it is assumed that the average family size is 4 persons, then the $3.00 per residence per month cost is the equivalent of a $9.00 annual cost per capita. This implies that solid waste management in conjunction with storm sewer and miscellaneous health regulations amounts to $13.50 per capita annually. If this is added to the average annual cost of water pollution control, then the total is $18.50. This indicates that the cost of all residue disposal ($18.50) is a larger per capita annual expense than the annual cost of water supply ($15.00).

The direct municipal costs for water supply and waste water disposal amounts to $20.00 per capita annually. This about 10% of total municipal expenditures. If the combined costs of solids wastes handling are considered, then an annual cost of $33.50 per capita is obtained which can be compared to a total city expenditure of $219 (210 + 9). This total is about 15% of the total. It can be concluded that the cost of obtaining a water supply and disposing of all water and solid wastes is a relatively small portion of the total per capita expenditures in a community.

At Ames, one might wonder what the resident receives for his annual expenditure of $5 for water quality management. The results of the 1970 status study using the water quality simulation model indicated that the stream water quality was below the desired quality levels for all frequencies of low-flow discharges greater than the 2-yr value. The need for expansion of the water pollution control plant indicates that the per capita cost will undoubtedly rise, since construction costs will be much higher (the 1950 plant cost $1,024,000 at the 25,000 PE capacity) and in addition the interest rates for municipal bonds has risen to an average level of about 6% (1969). However, the cost of water quality management has been low in comparison with other municipal expenditures and with general per capita expenditures for recreation, sports, liquor, cigarettes, etc. This places water quality management for enhancement purposes on an "ability-to-pay" basis, but in terms of consumer-taxpayer-voter consensus, there may be sufficient competition for his funds that there is little "willingness-to-pay" for improved levels of water quality.

3. The cost of water quality management in the future

a. Basic factors involved in the expansion of the Ames water pollution control plant The Iowa Water Pollution Control Commission (1967) has noted that expansion of the Ames water pollution control plant is to be made in the early 1970's. The results obtained in the field water quality studies and the computed results of the 1970 status study confirm this need for additional waste treatment. The studies initiated by Young et al. (1969) are directed toward this end, and have incorporated the initial results of the stream water quality research program. The computed results obtained under the 1990 conditions illustrate the problem of achieving quality enhancement. Three major factors were identified as important design parameters. These were: (1) the carbonaceous BOD load, (2) the nitrogenous BOD load caused by the ammonia (and organic nitrogen) and the related toxicity of ammonia in the stream, and (3) the nutrient load (phosphorus and nitrogen compounds) which activate and stimulate the algal community residing in the stream. All three relationships must receive concentrated attention in the planning and design of new plant facilities.

A detailed analysis of the costs of accomplishing plant redesign is beyond the scope of this study. Instead, general cost relationships were extracted from published literature or obtained from the State Health Department. These were used to evaluate the comparative cost of water pollution control in the future. The alternatives included in the 1990 design study were used in the economic evaluation. These were: (1) continued use of the trickling filter process, (2) revision of the present plant in a general expansion to the activated sludge process, (3) including use of the proposed Ames Reservoir for low-flow augmentation, and (4) use of a tertiary lagoon in addition to the activated sludge process and low-flow augmentation. Presumably this last alternative would assure an "ideal" level of stream water quality.

b. The cost of future water quality management Construction and operational cost data for water pollution control plants were obtained from studies by Frankel (1965a, 1965b) for trickling filter and activated sludge plants. Cost data for lagoon construction were obtained from the State Department of Health. The Ames Reservoir cost allocation for water quality purposes was obtained from the interim report of the U.S. Corps of Engineers (1964). All plant costs were evaluated on an annual basis using a 6% interest rate and a 20-yr period of repayment for municipal bonds (current rate, 1969). The annual per capita (population equivalent, PE, basis) costs were based on the average population equivalent projected for the period 1970-90 (65,000 PE). All data were adjusted to the 1969 price levels using the ENR cost index (Frankel, 1965a).

The results of the cost analysis are summarized in Table 120. The results show that the cost of continuing with the trickling filter alternative will increase from the present $5 per capita (PE) annually to about $8. The cost of the trickling filter and reservoir low-flow augmentation combination would be $12 per capita annually. The activated sludge alternative, if operated for optimum removal of ammonia (nitrification to nitrates) and phosphates (nutrient control), would result in a $10 annual per capita cost. Operation of the activated sludge plant in conjunction with the Ames Reservoir gives a combined annual cost of $14 per capita. Adding the tertiary lagoon to the activated-sludge-and-reservoir combination results in a total annual cost of about $16 annually.

c. Summary The highest level of waste treatment and water pollution control is achieved with the activated-sludge-reservoir-tertiary-lagoon combination. To achieve this "ideal" status of stream water quality in the Skunk River basin water quality management program, the annual cost per capita (PE basis) would increase from the present level of $5 to a future level of $15. A comparative description of these alternatives, as they relate to stream water quality enhancement, is illustrated in Fig. 88. This graphical description shows the alternatives available to the decision-maker in his quest for enhancement of stream water quality. It should be noted that the annual cost of low-flow augmentation, although a federal cost that will not be assessed directly to the local governments, can realistically be appraised as being payed by the local residents (who are the aforementioned taxpayer-consumer-voter entities).

Table 120. Comparative cost estimates of selected water pollution control alternatives at Ames, Iowa, for the 1990 design condition

Waste treatment alternative	Estimated cost of plant expansion	Equivalent annual cost	Annual cost of operation and maintenance	Continued level of expenditures for current facilities	Total annual cost for designated alternatives	
					Total	Per capita (PE)
1. Trickling filter	$2,700,000[a]	$235,000[b]	$ 65,000[a]	$200,000	$500,000	$ 7.70[c]
2. Activated sludge	4,000,000[a]	350,000	150,000	150,000[d]	650,000	10.00
3. Tertiary lagoon	700,000[e]	60,000	40,000	—	100,000	1.50
4. Ames Reservoir, low-flow augmentation	—	—	—	—	260,000[f]	4.00

[a]Cost data obtained from Frankel (1965a, 1965b) and compared with Iowa data.

[b]Based on 6% interest, 20-yr bonding period (1969 status).

[c]Average of projected population equivalent for period 1970-90, estimated to be 65,000 PE.

[d]Reduced to reflect incorporation of certain existing facilities into an activated sludge system.

[e]Based on 120 acres of land costing $800 per acre, 100 acres of lagoon area at $5,000 per acre, and physical facilities for inflow-outflow control at $100,000.

[f]Cost allocation of Corps of Engineers (1964), adjusted upward using ENR cost index (Frankel, 1965a).

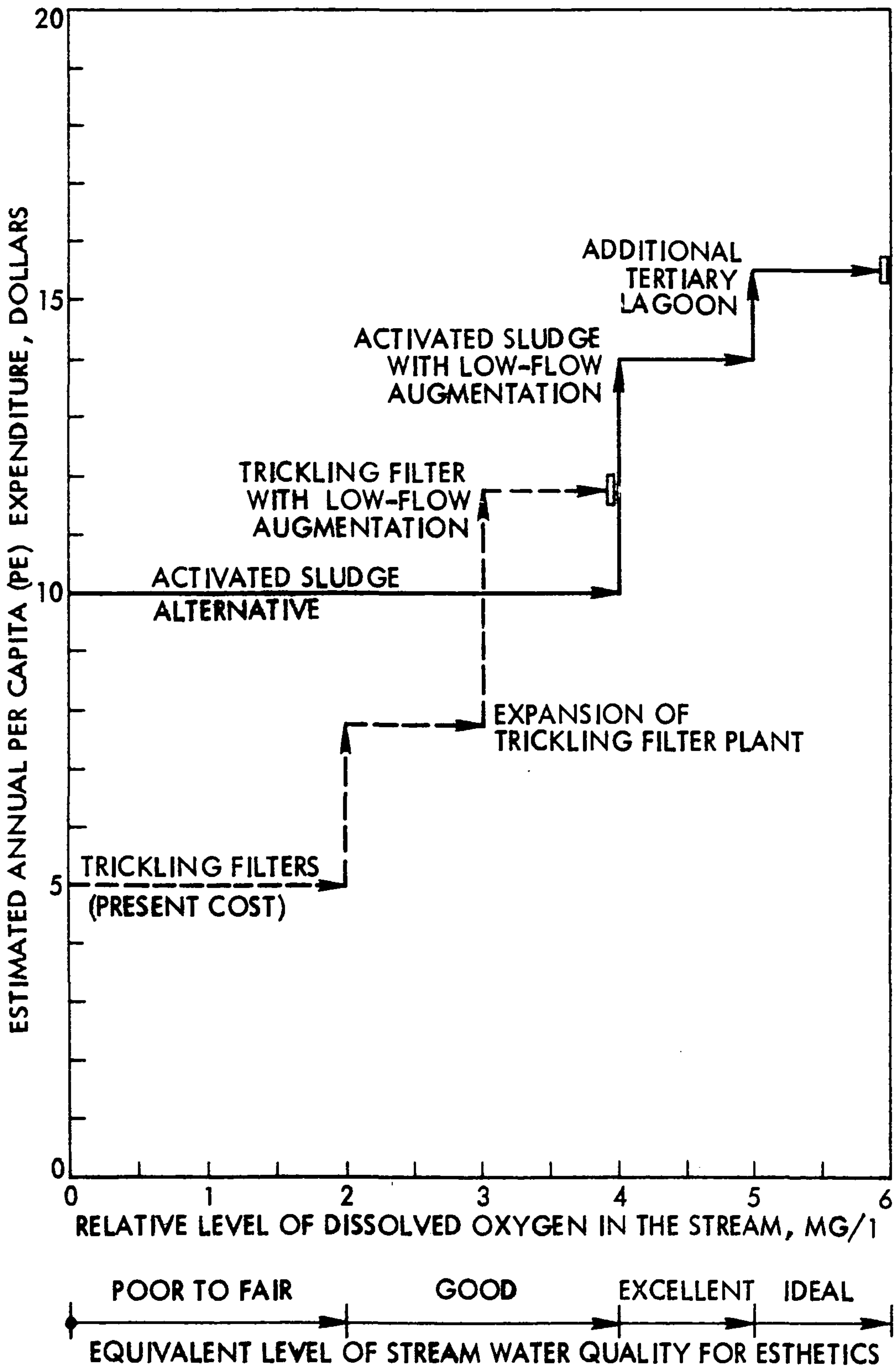

Fig. 88. Relative estimates of future per-capita expenditures required to enhance stream water quality to selected levels for the Skunk River at Ames, Iowa.

These results reveal that more dollars bring additional enhancement of water quality. However, in this case study of the Skunk River at Ames, Iowa, the concept of "esthetics" has been identified as the major beneficiary of improved levels of stream water quality. Therefore, enhancement beyond the least expensive alternative produces few if any additional benefits. The level of water quality to be associated with this least expensive alternative must be determined by the decision-makers, who in this case are the water quality regulatory agencies (local, state and federal). To meet the established state stream standards, low-flow augmentation must be included. Otherwise, increased emphasis must be placed on advanced (tertiary) methods of treating wastes, which have not been required to date in Iowa. Relaxation of the stream standards for identifiable assimilative reaches would also reduce the advanced treatment requirements and related expenditures.

Therefore, enhancement to meet the "ideal" water quality level illustrated in Fig. 88 may require the local residents to sacrifice other satisfactions for no measurable benefits. This is the dilemma or choice facing the decision-making bodies, and the same decision must also be made at a lower level by every taxpayer-consumer-voter entity. This economic study, although it is of a limited and simplified scope, provides a range of values within which alternatives may be weighed. It also illustrates the relative cost of enhancing stream water quality in Iowa associated with the municipal (and industrial) use of the stream for effluent disposal.

XV. CONCLUSIONS AND RECOMMENDATIONS FOR SELECTED RESEARCH NEEDS

A. Conclusions Resulting from the Statewide Studies

The body of knowledge that is needed to gain a thorough understanding of the many-faceted problem of water quality management in surface waters was compiled and presented in Vol. I. The three dimensions relating to enhancement of stream water quality through water pollution control were identified and discussed; these dimensions are the technical, the structural (or institutional), and the economic. Expression of the interrelationships among the three dimensions in mathematical terms has been reviewed and summarized. Recommended levels of water quality for the recognized beneficial uses of water have been collated and summarized from various sources. Mathematical models for simulating stream water quality which have been developed in various parts of the nation are presented for potential application in Iowa.

The results of a comprehensive stream water quality research program were included in Vol. II, with the supporting data and results placed in Vol. III. This research effort was directed toward the determination of existing water quality levels in a selected study stream (the Skunk River) and of its response to effluents discharged from the several sources of pollution. Forecasting of future water quality levels was a concluding phase of this effort. Economic aspects of water pollution control and the relative costs of enhancing stream water quality were also analyzed.

The hydrologic study of low-flow characteristics of Iowa streams, as related to water pollution control and water quality management needs, resulted in the identification of three water quality regions. Region I consists of the streams located in the far northeast part of Iowa; these streams and rivers have well-sustained low flows and have been assigned an "ideal" status for water quality management purposes. They have an excellent assimilative capacity for municipal effluents or other treated waste discharges, with higher discharges and lower average water temperatures in this region than in any other region.

Region II consists of the streams in the Iowa-Cedar and Wapsipinicon River basins, and local areas along the Mississippi River. These have been assigned a "good" status, with substantial low-flow discharge during drought periods. Because of the size of the major rivers in Region II, a large volume of dilution water is available for water quality management purposes. The municipalities in this region have a decided economic advantage with regard to the waste assimilative capacity of the streams for both municipal and industrial effluents.

The remaining two-thirds of the state (central, southern and western counties) has been assigned a "poor" status, with limited usefulness for waste assimilation. In this latter category, Region III, many streams of small to intermediate size will be dry during parts of almost every year. Frequently, effluent discharge from water pollution control plants will be the only contribution to streamflow. It will be difficult to meet established stream standards (at the 7-day, 10-yr low-flow magnitude) in these streams. Typical Region III streams include the Skunk River, the Des Moines River, and all southern and western streams.

The general capability of the streams and rivers in the three regions to assimilate treated waste discharges has been expressed in terms of the amount of biochemical oxygen demanding material permitted in the stream following mixing. Dilution requirements and drainage area low-flow relationships have been computed for average summer conditions.

B. Conclusions Resulting from the Case Study of the Skunk River Basin

The general status of water quality in the Skunk River basin was surveyed. Beneficial uses of water and related water quality control problems have been outlined. Rural domestic problems are minimized as the farm group population diminishes. Agricultural pollution problems relate primarily to livestock, poultry, and crop production. The use of agricultural fertilizers has a real potential for depositing nutrients (nitrates and phosphates) in the stream system.

The municipal waste problem was studied as the key item influenced by the establishment of the Iowa stream water quality standards by the state regulating agency. The municipal and industrial sources of pollution were identified and discussed. Population growth has been concentrated in regional centers (county seats or other industrial communities). The largest population center which is growing rapidly is the city of Ames. The Skunk River at Ames became the focal point of water quality studies in the case study of stream water quality.

Population projections were made in the Ames area for urban and rural areas. Four population projection models were developed and used in forecasting the residential and student population at Ames. The future population levels were found to be influenced by the student enrollment at Iowa State University. This influence was expressed quantitatively in the mathematical models for population projection. Some leveling off of the total population of Ames is forecast in the 1985-1990 period as the decrease in live births (and an associated decrease in the birth rate) in the late 1960's influences the student age population group. Three ranges of population levels were summarized: a high range, a medium range, and a low range. Using the population projections and related water use and waste water volumes experienced since 1950, estimates of water use and waste water volumes were made for the period 1970-2020. The efficiency of the present water pollution control plant was studied to obtain estimates which could represent a 1970 status level. A need for plant expansion is forecast for the early 1970's.

An initial but comprehensive analysis has been made of the characteristics of effluents from three types of waste treatment processes existing in or near the basin. These include a trickling filter plant, an activated sludge plant, and a waste stabilization pond. Temporal analysis of the results of BOD progression, ammonia nitrification, and removal efficiencies has provided a new insight of the waste treatment process. Published results for raw sewage BOD progression were included in the quantitative study of deoxygenation rates and ultimate BOD values.

Mathematical treatment of the research results led to the development of a "modified monomolecular model" for simulating the BOD progression with time. BOD results for both raw sewage and treated effluents were included in the study. The results obtained with this model provide a more accurate prediction of BOD than either the first-order or the second-order mathematical model. However, it was concluded that all three can predict with an acceptable degree of accuracy the results obtained from biological processes. The first-order model was accepted for stream studies and for application in a proposed mathematical model for simulating water quality levels in streams.

A comprehensive case study of the Skunk River at Ames, Iowa, provided a wealth of water quality data. The response of the stream environment to effluents discharged from water pollution control plants was studied in detail. Causative relationships were developed for selected water quality parameters. The factors which were found to be important in maintaining adequate dissolved oxygen in the stream were: (1) organic waste loads of the carbonaceous category, (2) ammonia nitrification, (3) boundary BOD additions at the channel bottom, the air-water interface, and from decaying aquatic plants and algae, (4) atmospheric reaeration which occurs at a high level in the smaller streams, and (5) the tremendous impact of the algal environment on stream behavior. Several useful (and quantitative) relationships were developed in the analytical phase of the stream water quality studies.

The water quality field studies formed the basis for development of a new mathematical model for simulating water quality levels in a stream. The algal oxygen productivity (photosynthetic oxygen contribution in the daytime and respiration liability at night) has been included as a major factor in the model. This permits the stream to respond (mathematically) to increased levels of nutrients at waste discharge points, and results in an increased algal productivity concept in the assimilative reach.

A complex and comprehensive digital computer model was developed for mathematically describing water quality in a stream. This simulation model has been labeled the "ISU water quality model." Verification of the model was achieved using the observations obtained in the water quality field studies. A 1970 status study was made, with reasonable forecasts being obtained for the now-existing conditions. The model was then used to forecast the 1990 design level to represent the 1970-2000 planning period. Alternative water pollution control measures studied were: (1) continued use of the trickling filter process, (2) introduction of the activated sludge process, (3) low-flow augmentation using the proposed Ames Reservoir, and (4) additional use of a tertiary lagoon for temporary waste storage during the winter season.

The analytical studies made using the ISU water quality model have illustrated a three-fold problem facing the field of water quality management. The three factors primarily associated with water quality deterioration in assimilative reaches are: (1) the carbonaceous BOD and its effect on the DO resource, (2) ammonia nitrification and its effect of the same DO resource, and in presenting a toxicity problem to aquatic life, and (3) the role of nutrients in causing a rapid and substantial algal growth in the assimilative reach (as well as in clean water areas). With the simulation model, the sensitivity of water quality improvement programs to increased removal efficiencies of each can be explored.

An initial appraisal has been made of the economics of water quality management for the study reach. At Ames, the cost of water pollution control and related management aspects has been evaluated on a per capita basis. The cost of water pollution activities remains low. Ames residents are paying only one-third as much for waste disposal as for water supply. The cost of all waste disposal (liquid and solid residues) approaches the annual per capita cost of the water supply. However, enhancement of water quality in the future may result in equivalent waste water costs and water supply costs. Although part of this cost is borne by the federal government as an adjunct to the proposed Ames Reservoir, the real cost (including the federal income tax concept) still remains with the local resident. The cost of water quality management, and related environmental water and solid waste disposal, varies from a per capita level of $5 today to an estimated level of almost $15 in the future. Although this appears to be within the "ability-to-pay" concept, it remains to be seen whether there is a "willingness-to-pay." Attitudes, education, and public relations have been outlined as the key to successful water quality management for future enhancement of stream water quality.

C. Recommendations for Selected Water Quality Research

The research program reported in this treatise lays the foundation for a broad research program in stream water quality, water pollution control, and water quality management. The following areas have been selected for major emphasis:

1. Additional research is recommended to define the nature of effluents from the several types of waste treatment processes used or proposed for use in Iowa. Division of the waste loads (through laboratory analyses) into the carbonaceous and nitrogenous fractions is imperative, and plant efficiencies should be reported for each. Nutrient loads and concentrations (primarily the phosphorus and nitrogen compounds) need to be studied and evaluated for these several types of waste treatment processes over various seasons of the year.

2. Additional studies of selected streams should be made on a continued sampling basis and on a year-round schedule. Winter conditions are of particular interest, as is the rate of algal growth and productivity. Winter algae relationships also need to be studied. Various biological processes need to be studied at the low temperatures existing in Iowa streams in the winter season. Assimilative reaches downstream of selected water pollution control plants also need to be studied. Of particular interest is the fate of ammonia downstream of activated sludge plants. The effect upon the receiving stream of intermittent dumping of waste stabilization ponds versus continuous outflow, a problem identified in the field studies, needs further study.

3. Extension of the ISU water quality simulation model to make it more of a general use model for other streams in Iowa is recommended. It could then be used for studying other streams in Iowa and in the midwest. Additional work in the area of developing an even more rigorous model would be beneficial. Application of the ISU water quality model to the problem of predicting stream changes resulting from additional waste treatment in water pollution control plants is

recommended. The effect of the three major factors, (1) additional carbonaceous BOD removal, (2) ammonia stripping or nitrification of the waste, and (3) nutrient control to limit the algal growth in the assimilative reach, can be studied in turn to determine the sensitivity of the stream environment to increased treatment. This research might disclose which of the three areas should receive the most design attention and in which the greatest cost savings might accrue.

4. Several interdisciplinary studies of the stream environment are recommended. The algal environment is in particular need of study. Preliminary studies have shown the effect of pollution on the diatom communities; however, the green algae and other forms are in urgent need of study also. Primary attention should now be directed to the fixed or attached varieties of algae in assimilative reaches, since the research results have shown this to be the problem area during low-flow periods. Algal oxygen productivity (and related respiration values) need to be studied quantitatively.

5. Additional economic studies of the operation and maintenance aspects of water pollution control plants are proposed. This phase of water quality management has been neglected, yet the success of water quality management programs depends upon efficient and continuous operation of the treatment plants. Sociological implications are inherent in this problem and should be pursued.

6. A regional water quality management study is proposed for application to the Iowa environment. Because of the observed independency of the assimilative reaches in most circumstances, these studies should be directed to (1) the need and usefulness of metropolitan water

quality management programs including central treatment and/or central control and operation of spatially located plants, and (2) regional management on a partial drainage basin basis of the municipal water pollution control plants which are operating on the "independent assimilative reach" basis. The opportunity to enhance the stream water quality or to achieve a designated level of water quality at a lower cost to the region would be explored in these studies. The socio-economic aspect of personnel and organization structure for regional management of water quality is a related item to pursue.

These recommendations illustrate that many water quality problems remain to be solved. Establishment of stream water quality standards has not necessarily or magically resulted in satisfactory levels of water quality in Iowa streams. The established levels have served to point out problem areas of concern, and that additional research is needed to determine not only if enhancement is possible, but if relaxation of certain standards can be permitted and under what circumstances relaxation of standards might be reasonable. This study has shown that man's use of the stream system has resulted in many complex interactions, and only through additional research will it be possible to truly enhance the quality of the water in Iowa streams.

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XVII. ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance provided by numerous people during a long and arduous research program. First acknowledgment is given to Dr. E. Robert Baumann and Dr. John F. Timmons for their encouragement to embark on a new research venture, water quality in Iowa streams. It is hoped that the guidance, stimulation and patience of these two individuals have been rewarded in part by the results contained in this treatise. The author is particularly indebted to Dr. Baumann for serving as major professor and for his administrative assistance in conducting this phase of sanitary engineering research at Iowa State University. Additional acknowledgment is granted to the other three members of the author's examining committee, Dr. John L. Cleasby, Dr. Howard P. Johnson, and Dr. Donald F. Young.

A special tribute is due Dr. Harris F. Seidel, Director of water supply and pollution control for the city of Ames, Mr. Ralph W. Briley, Chief Operator of the water pollution control plant, and their dedicated staff and operating personnel. Success of the field water quality studies can be attributed to their assistance in conducting the many tests and in stream sampling, in the willingness of this group to decrease the operational efficiency of the plant for the determination of the stream assimilative capacity, and in cooperating in every feasible manner to make the research program a success. The operating role of all water pollution control plants in Iowa, and their importance in stream water quality control programs, receive the author's vote of appreciation. Additional recognition is made of the several city offices and departments in Ames who supplied and interpreted data for the case study. The cooperation of the Marshalltown water pollution control plant personnel and of the town of Jewell is also appreciated.

The author also wishes to express his appreciation to the several state and federal agencies that have participated and assisted in many ways: the U.S. Geological Survey, Iowa City, with special thanks to the personnel of the Fort Dodge subdistrict office for their assistance in measuring streamflow and providing stage and discharge records; the U.S. Corps of Engineers, Rock Island District, for data and for continued financial support of the Skunk River basin water resources research program; the Iowa State Department of Health and the Iowa Water Pollution Control Commission for supplying data and reports; and to the Iowa Natural Resources Council for data and water resources bulletins.

A great deal of appreciation is expressed to the graduate students, past and present, of the sanitary engineering section of the Department of Civil Engineering. Their assistance in conducting stream sampling surveys, diurnal dissolved oxygen and dye tracer studies, and in listening to the aspirations and complaints of the author were all of immeasurable value. Also appreciated are all of the many hours of effort expended by the undergraduate students, principally in civil engineering but also in chemistry, who served capably as hourly employees in various phases of the research program.

Several departments and groups at Iowa State University indirectly assisted in the research program. The assistance and support of

Dr. Carl E. Ekberg, Head, Department of Civil Engineering and of the secretarial staff is warmly acknowledged. The technical assistance of the Engineering Research Institute administrative staff and shop personnel, the Iowa State Computation Center, and many others is gratefully acknowledged. The author is especially indebted to Mr. Robert L. Johnson, Instructor in Civil Engineering, who provided both technical assistance and moral support in the development of various computer techniques including the ISU water quality model.

The research was supported by the Engineering Research Institute, and in part by the Iowa State Water Resources Research Institute through funds administered by the Office of Water Resources Research, U.S. Department of Interior, Project A-001-IA. The additional support of the city of Ames and the Rock Island District, Corps of Engineers during several related phases of the research program with other on-going programs is duly recognized.

The author must give his warmest tribute and acknowledgment to his wife, Marianne, his daughter, Linda, and son, Gregory, for their generosity and sacrifice of many hours of family life during the course of the research program. Their assistance during the final manuscript preparation, proofing and printing is also recognized. The ability and assistance of Mrs. Letha Osmundson, who typed the lengthy manuscript most readily and ably, is also recognized and gratefully acknowledged.

PHYSICAL AND ECONOMIC FACTORS ASSOCIATED WITH THE

ESTABLISHMENT OF STREAM WATER QUALITY STANDARDS

by

Merwin Dean Dougal

VOLUME III of III

A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Sanitary Engineering

Approved:

In Charge of Major Work

Head of Major Department

Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1969

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PHYSICAL AND ECONOMIC FACTORS ASSOCIATED WITH THE ESTABLISHMENT OF STREAM WATER QUALITY STANDARDS

A STUDY IN THREE VOLUMES

PREFACE

The stream system in a river basin is an integral part of man's total environment. Its natural function is to return water to the ocean, the ultimate sink for all of the earth's residues as well as being the basic source of atmospheric moisture. The stream system serves also as a natural habitat for various flora and fauna which contribute to a healthy, productive aquatic environment. Man's activities in the twentieth century period of industrialization have accelerated the degradation of the water environment. Serious conflicts related to water quality have arisen among the groups making beneficial use of the surface water resource. Concern at all levels of government has resulted in increased attention and action directed toward the solution of water pollution problems.

Recent research in water quality has been replete in all three dimensions of the water quality framework — the technical, the economic and the institutional. Problem areas such as public health, resources use, technical innovations, economic alternatives, social aspects, and political-institutional-management relationships have been identified and studied through research endeavors, One of the principal objectives of current research is the development of methods of obtaining an optimal level of water quality in a stream commensurate with man's desired uses and the relevant economic constraints. A corollary objective

is determining the most economical solution for treating a region's wastes to obtain a desired minimum level of stream water quality, allocating specific treatment plant efficiencies among the several water use groups competing for the convenience of the stream's water conveyance mechanism.

In a study confined within a single dimension of the threefold technical-economic-institutional framework, it is likely that concepts and data from other dimensions are lacking. This frequently results in the introduction of over-simplifying assumptions. A comprehensive study of methods for achieving selected water quality objectives should include the necessary elements of all three dimensions. Several case studies of selected river basins have been made recently to illustrate the application of newer methods of technical and economic analyses. However, no comprehensive studies encompassing these three dimensions have been made for Iowa, and the status of the interrelated elements has not been explored fully in this region.

This treatise is devoted also to the water pollution problem, with specific emphasis on problems in Iowa. Adoption and enforcement of the Iowa water quality standards for surface waters have as their objective the enhancement of water quality. The degree to which this enhancement can be realized and the related economic impact of such enhancement has received major attention in this study. The purposes for which this detailed study was conducted include

- to explore in a broad manner the underlying principles of each of the three dimensions (technical-economic-institutional) as they relate to stream water quality standards in Iowa,

- to list and evaluate the parameters that will influence water quality in Iowa streams including those that are of greatest concern in the establishment and enforcement of stream standards,
- to review and evaluate the hydrologic characteristics of Iowa streams as these characteristics become determinants in the water quality enhancement program,
- to identify the nature and characteristics of municipal effluents discharged to the stream environment,
- to study the response of a typical central Iowa stream as it receives waste discharges from a municipal water pollution control plant, and
- to determine for an urban area the economic importance of water pollution control and stream water quality enhancement, and the related impact of water quality standards on expenditures for a stream improvement program.

This treatise on water quality is divided into three parts. Vol. I is devoted to the initial two purposes listed above, and includes (1) a historical review of the water pollution problem, (2) identification and discussion of the potential effects of pollutants, and (3) application concepts for establishment and enforcement of water quality standards. Vol. II is devoted to a detailed study of Iowa stream conditions as outlined in the last four of the six purposes listed above. These specific studies include (1) a general study of Iowa stream water quality problems and availability of data, (2) the relationship of hydrologic characteristics and assimilative capacities of Iowa streams, and (3) a comprehensive technical-economic case study of the Skunk River at Ames, Iowa. Vol. III consists of the appendices for the detailed studies, and includes (1) basic data for the study, (2) selected hydrologic and water quality study information and results, (3) tabulated results of the water quality response model for the study area, and

(4) other supporting data.

It was the goal of this research endeavor to compile in one document the pertinent information concerning water quality in surface waters, and to provide through the comprehensive case study a means of directing future research efforts and activities. These are outlined in the concluding section of Vol. II. The case study permitted observing and measuring the response of the stream environment to man's water quality inputs, provided an opportunity for concentrated research and application methods, and hopefully produced meaningful results for a river basin in central Iowa where a rapidly expanding urban area is located.

XVIII. APPENDIX A

A. Low-Flow Discharge Data, Skunk River near Ames, Iowa

1. <u>Summer season, annual minimum low-flow values for selected durations</u>

Table A-1. Annual minimum low-flow discharges, Skunk River near Ames, summer season values, 1934-1967, for 3-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	11-31-33	0.5	18	1951	12-09-50	0.9
2	1935	10-02-34	0.0	19	1952	11-11-51	25.3
3	1936	12-22-35	6.4	20	1953	01-05-53	1.0
4	1937	12-02-36	0.2	21	1954	01-05-54	0.0
5	1938	01-04-38	0.3	22	1955	11-13-54	4.6
6	1939	12-04-38	3.0	23	1956	12-20-55	0.0
7	1940	12-18-39	0.2	24	1957	01-13-57	0.0
8	1941	10-25-40	0.5	25	1958	11-26-57	6.1
9	1942	12-01-41	2.0	26	1959	02-28-59	5.4
10	1943	11-25-42	22.0	27	1960	11-22-59	7.3
11	1944	01-29-44	53.0	28	1961	12-15-60	13.0
12	1945	02-29-45	22.3	29	1962	12-11-60	13.0
13	1946	02-24-46	5.9	30	1963	12-29-62	22.0
14	1947	12-22-46	4.7	31	1964	01-16-64	0.5
15	1948	12-24-47	1.6	32	1965	01-09-65	0.6
16	1949	01-17-49	0.3	33	1966	11-17-65	1.2
17	1950	12-30-49	0.3	34	1967	01-12-67	0.1

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-2. Annual minimum low-flow discharges, Skunk River near Ames, summer season values, 1934-1967, for 7-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	01-10-34	0.9	18	1951	12-10-50	1.2
2	1935	11-29-34	0.0	19	1952	11-14-51	28.3
3	1936	12-22-35	7.4	20	1953	01-08-53	1.1
4	1937	12-04-36	0.2	21	1954	01-05-54	0.0
5	1938	01-08-38	0.3	22	1955	11-13-54	4.8
6	1939	12-04-38	3.4	23	1956	12-20-55	0.0
7	1940	12-20-39	0.2	24	1957	12-02-56	0.0
8	1941	10-26-40	0.6	25	1958	11-26-57	6.3
9	1942	12-01-41	2.3	26	1959	02-29-59	7.6
10	1943	11-25-42	28.6	27	1960	11-22-59	12.7
11	1944	01-30-44	54.9	28	1961	12-16-60	15.8
12	1945	02-29-45	23.1	29	1962	12-02-61	16.0
13	1946	01-16-46	7.1	30	1963	12-29-62	23.1
14	1947	12-23-46	5.7	31	1964	01-16-64	0.6
15	1948	12-26-47	2.0	32	1965	01-09-65	0.6
16	1949	01-18-49	0.3	33	1966	11-21-65	1.6
17	1950	12-02-49	0.3	34	1967	01-14-67	0.2

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-3. Annual minimum low-flow discharges, Skunk River near Ames, summer season values, 1934-1967, for 14-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	01-15-34	1.1	18	1951	12-10-50	2.9
2	1935	10-02-34	0.01	19	1952	11-14-51	36.4
3	1936	12-23-35	11.0	20	1953	01-15-53	1.4
4	1937	12-04-36	0.3	21	1954	01-10-54	0.04
5	1938	01-09-38	0.4	22	1955	11-16-54	5.1
6	1939	12-04-38	4.6	23	1956	12-20-55	0.01
7	1940	12-25-39	0.3	24	1957	11-12-56	0.00
8	1941	10-28-40	0.8	25	1958	01-07-58	7.0
9	1942	12-01-41	3.3	26	1959	02-16-59	8.0
10	1943	11-25-42	40.1	27	1960	11-22-59	14.0
11	1944	01-30-44	58.9	28	1961	12-18-60	23.1
12	1945	02-24-45	24.1	29	1962	12-11-61	17.1
13	1946	01-23-46	7.3	30	1963	12-30-62	25.6
14	1947	12-27-46	10.0	31	1964	01-17-64	0.8
15	1948	12-29-47	2.6	32	1965	01-15-65	0.7
16	1949	01-23-49	0.6	33	1966	11-24-65	2.0
17	1950	12-02-49	0.4	34	1967	01-14-67	0.5

[a]Computer analysis of U.S.G.S. data.

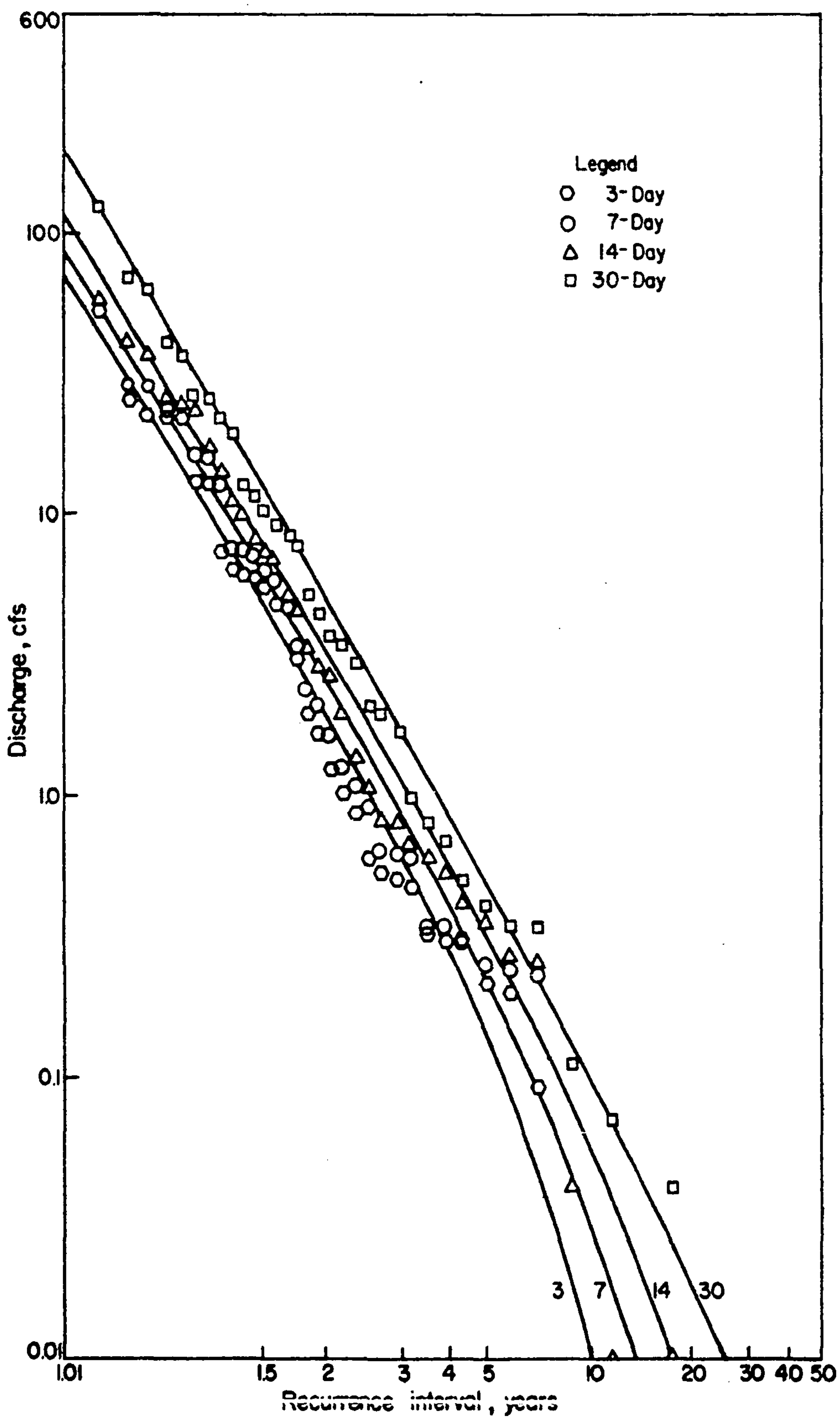
[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-4. Annual minimum low-flow discharges, Skunk River near Ames, summer season values, 1934-1967, for 30-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	02-27-34	3.0	18	1951	12-20-50	3.6
2	1935	11-29-34	0.04	19	1952	11-26-51	62.4
3	1936	12-22-35	12.8	20	1953	01-30-53	1.7
4	1937	12-04-36	0.3	21	1954	01-20-54	0.07
5	1938	01-15-38	0.5	22	1955	11-17-54	10.1
6	1939	12-10-38	11.4	23	1956	02-11-56	0.11
7	1940	01-06-40	0.3	24	1957	11-12-56	0.00
8	1941	10-28-40	1.9	25	1958	01-22-58	9.0
9	1942	12-01-41	4.5	26	1959	02-16-59	8.4
10	1943	12-02-42	124.6	27	1960	11-22-59	21.7
11	1944	02-06-44	69.5	28	1961	11-28-60	40.9
12	1945	02-22-45	26.4	29	1962	12-28-61	25.2
13	1946	02-05-46	7.6	30	1963	01-03-63	36.4
14	1947	12-06-46	19.0	31	1964	01-18-64	2.0
15	1948	01-02-48	3.4	32	1965	01-29-65	0.8
16	1949	01-25-49	0.7	33	1966	11-29-65	5.2
17	1950	01-19-50	0.4	34	1967	01-16-67	1.0

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.


Legend
3-Day
7-Day
14-Day
30-Day
Discharge, cfs
600
100
10
1.0
0.1
0.01
3
7
14
30
1.01
1.5
2
3
4
5
10
20
30
40
50
Recurrence interval, years

2. Winter season, annual minimum low-flow values for selected durations

Table A-5. Annual minimum low-flow discharges, Skunk River near Ames, winter season values, 1934-1967, for 3-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	04-08-34	0.4	18	1951	05-11-51	0.7
2	1935	04-06-35	19.3	19	1952	04-13-52	23.3
3	1936	05-24-36	18.0	20	1953	03-02-53	1.9
4	1937	05-10-37	0.7	21	1954	05-04-54	0.0
5	1938	04-12-38	0.2	22	1955	05-15-55	12.7
6	1939	04-01-39	6.0	23	1956	06-17-56	0.0
7	1940	05-01-40	0.1	24	1957	04-16-57	2.8
8	1941	03-18-41	27.3	25	1958	05-22-58	14.0
9	1942	04-08-42	38.3	26	1959	05-24-59	1.5
10	1943	04-26-43	23.3	27	1960	06-20-60	32.0
11	1944	04-15-44	14.0	28	1961	05-01-61	3.6
12	1945	04-09-45	9.3	29	1962	04-31-62	50.0
13	1946	03-23-46	2.2	30	1963	04-30-63	3.6
14	1947	06-07-47	11.0	31	1964	03-30-64	0.2
15	1948	05-15-48	1.5	32	1965	05-04-65	0.7
16	1949	03-29-49	2.9	33	1966	05-06-66	24.0
17	1950	05-06-50	0.4	34	1967	04-20-67	0.7

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-6. Annual minimum low-flow discharges, Skunk River near Ames, winter season values, 1934-1967, for 7-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	04-12-34	0.5	18	1951	05-11-51	0.7
2	1935	04-06-35	19.6	19	1952	04-13-52	24.3
3	1936	05-25-36	19.3	20	1953	03-02-53	2.1
4	1937	05-10-37	0.8	21	1954	05-04-54	0.0
5	1938	04-16-38	0.2	22	1955	05-16-55	13.4
6	1939	04-03-39	7.6	23	1956	06-17-56	0.0
7	1940	05-01-40	0.1	24	1957	04-18-57	2.9
8	1941	03-19-41	28.4	25	1958	05-22-58	14.0
9	1942	04-10-42	42.1	26	1959	05-25-59	1.6
10	1943	04-30-43	25.0	27	1960	06-21-60	32.3
11	1944	04-17-44	15.4	28	1961	05-04-61	3.7
12	1945	04-13-45	9.7	29	1962	05-03-62	50.4
13	1946	03-26-46	2.4	30	1963	05-01-63	3.7
14	1947	06-08-47	12.4	31	1964	03-24-64	0.3
15	1948	05-16-48	1.6	32	1965	05-04-65	0.7
16	1949	04-02-49	3.5	33	1966	05-07-66	24.8
17	1950	05-06-50	0.4	34	1967	04-21-67	1.0

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-7. Annual minimum low-flow discharges, Skunk River near Ames, winter season values, 1934-1967, for 14-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	04-17-34	0.5	18	1951	05-11-51	0.7
2	1935	04-07-35	23.6	19	1952	04-13-52	25.9
3	1936	05-26-36	22.7	20	1953	03-07-53	2.7
4	1937	05-16-37	0.9	21	1954	05-04-54	0.0
5	1938	04-22-38	0.2	22	1955	05-16-55	14.6
6	1939	04-04-39	12.0	23	1956	05-23-56	0.0
7	1940	05-01-40	0.1	24	1957	04-20-57	3.5
8	1941	03-24-41	36.6	25	1958	05-22-58	14.4
9	1942	04-14-42	55.3	26	1959	05-25-59	1.6
10	1943	05-02-43	27.4	27	1960	06-23-60	33.1
11	1944	04-20-44	17.1	28	1961	05-09-61	4.0
12	1945	04-19-45	10.2	29	1962	05-04-62	52.5
13	1946	03-31-46	2.6	30	1963	05-05-63	3.9
14	1947	06-11-47	16.1	31	1964	03-31-64	0.3
15	1948	05-16-48	1.7	32	1965	05-04-65	1.2
16	1949	04-03-49	3.9	33	1966	05-07-66	29.8
17	1950	05-06-50	0.4	34	1967	04-21-67	1.4

[a]Computer analysis of U.S.G.S. data.

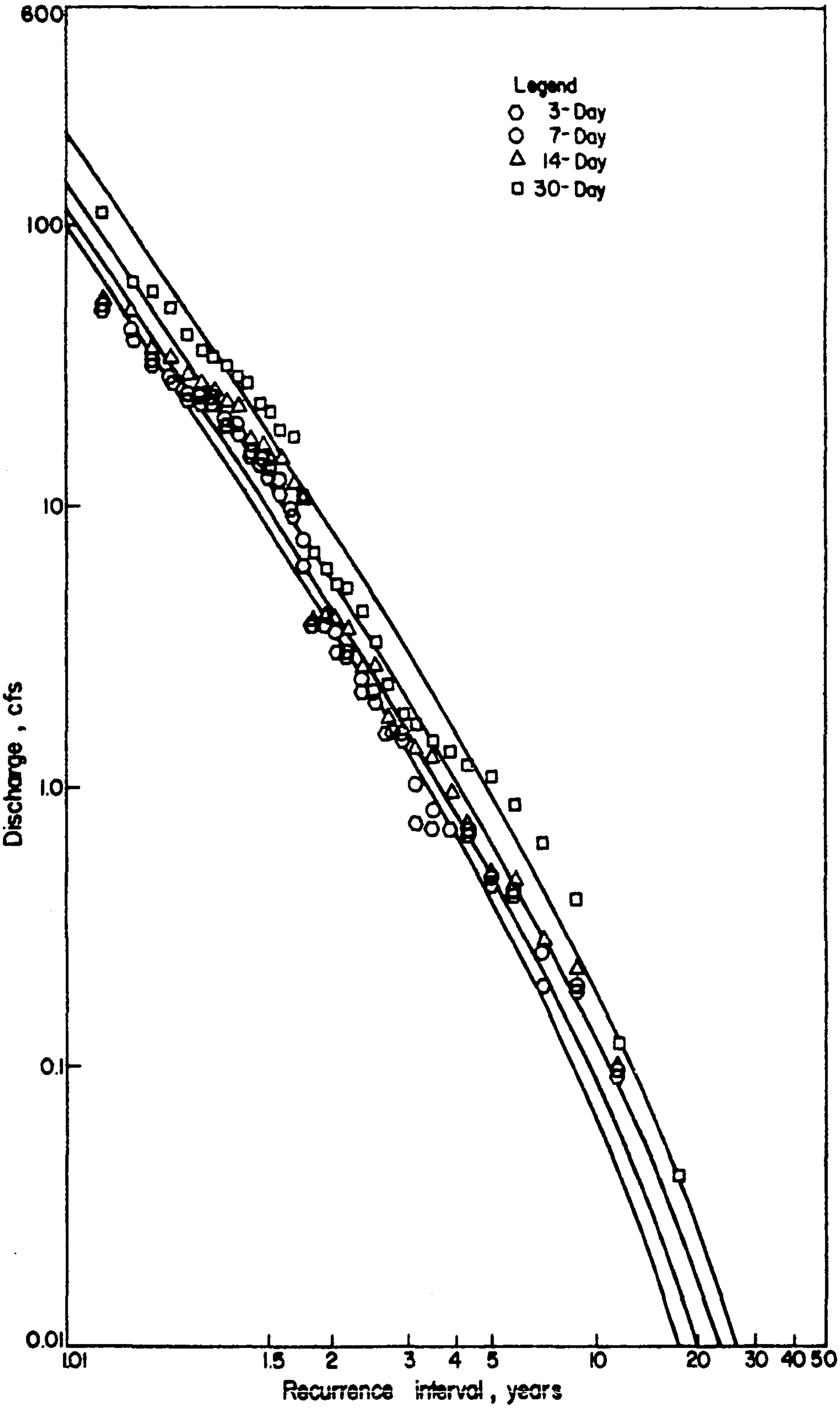
[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-8. Annual minimum low-flow discharges, Skunk River near Ames, winter season values, 1934-1967, for 30-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1934	04-19-34	1.0	18	1951	05-18-51	1.2
2	1935	04-08-35	40.1	19	1952	04-14-52	31.6
3	1936	05-27-36	29.0	20	1953	04-13-53	3.3
4	1937	05-16-37	1.3	21	1954	05-09-54	0.04
5	1938	03-28-38	0.4	22	1955	05-17-55	17.4
6	1939	04-04-39	18.6	23	1956	05-23-56	0.00
7	1940	05-07-40	0.1	24	1957	04-20-57	6.0
8	1941	05-12-41	51.8	25	1958	05-22-58	22.7
9	1942	04-15-42	113.7	26	1959	05-25-59	1.6
10	1943	05-02-43	33.3	27	1960	06-26-60	35.9
11	1944	04-25-44	21.3	28	1961	05-11-61	6.6
12	1945	04-21-45	10.6	29	1962	05-04-62	62.1
13	1946	04-04-46	4.2	30	1963	05-14-63	5.2
14	1947	04-24-47	27.6	31	1964	04-13-64	0.8
15	1948	05-26-48	2.3	32	1965	05-05-65	1.8
16	1949	04-03-49	5.1	33	1966	06-16-66	58.6
17	1950	05-07-50	0.6	34	1967	04-23-67	1.4

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.


Legend
3-Day
7-Day
14-Day
30-Day
600
100
10
1.0
0.1
0.01
Discharge, cfs
1.01
1.5
2
3
4
5
10
20
30
40
50
Recurrence interval, years

B. Low-Flow Discharge Data, Skunk River below Squaw Creek

1. Summer season, annual minimum low-flow values for selected durations

Table A-9. Annual minimum low-flow discharges, Skunk River below Squaw Creek, summer season values, 1953-1967, for 3-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	01-05-53	1.30	4.93
2	1954	02-29-54	0.30	2.36
3	1955	11-12-54	8.0	10.68
4	1956	02-28-56	0.23	2.47
5	1957	02-07-57	0.0	3.17
6	1958	01-06-58	8.03	11.19
7	1959	02-28-59	8.00	10.51
8	1960	11-22-59	8.80	13.01
9	1961	12-15-60	24.66	28.95
10	1962	12-11-61	28.33	32.54
11	1963	12-29-62	26.0	30.15
12	1964	02-15-64	1.73	6.08
13	1965	01-28-65	0.80	5.60
14	1966	11-24-65	2.53	7.04
15	1967	01-12-67	0.10	4.99

[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-10. Annual minimum low-flow discharges, Skunk River below Squaw Creek, summer season values, 1953-1967, for 7-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	01-08-53	1.53	4.87
2	1954	02-28-54	0.30	2.46
3	1955	11-16-54	8.93	11.64
4	1956	02-27-56	0.30	2.62
5	1957	02-07-57	0.0	3.04
6	1958	01-07-58	9.00	12.37
7	1959	02-14-59	11.28	14.73
8	1960	11-22-59	18.48	22.58
9	1961	12-15-60	28.85	33.01
10	1962	12-11-61	33.14	37.39
11	1963	12-29-62	29.43	33.55
12	1964	01-16-64	1.77	6.39
13	1965	01-30-65	0.85	5.42
14	1966	11-24-65	3.36	8.00
15	1967	01-14-67	0.14	5.02

[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-11. Annual minimum low-flow discharges, Skunk River below Squaw Creek, summer season values, 1953-1967, for 14-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	01-15-53	1.86	5.11
2	1954	02-17-54	0.56	2.92
3	1955	11-16-54	9.77	12.41
4	1956	02-27-56	0.32	2.87
5	1957	02-07-57	0.0	2.99
6	1958	01-07-58	12.21	15.57
7	1959	02-14-59	11.43	14.87
8	1960	11-22-59	22.67	26.73
9	1961	12-18-60	41.86	46.14
10	1962	12-11-61	35.28	39.45
11	1963	12-30-62	33.21	37.38
12	1964	01-16-64	1.88	6.53
13	1965	01-31-65	0.88	5.42
14	1966	11-28-65	3.80	8.48
15	1967	01-16-67	0.25	5.00

[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

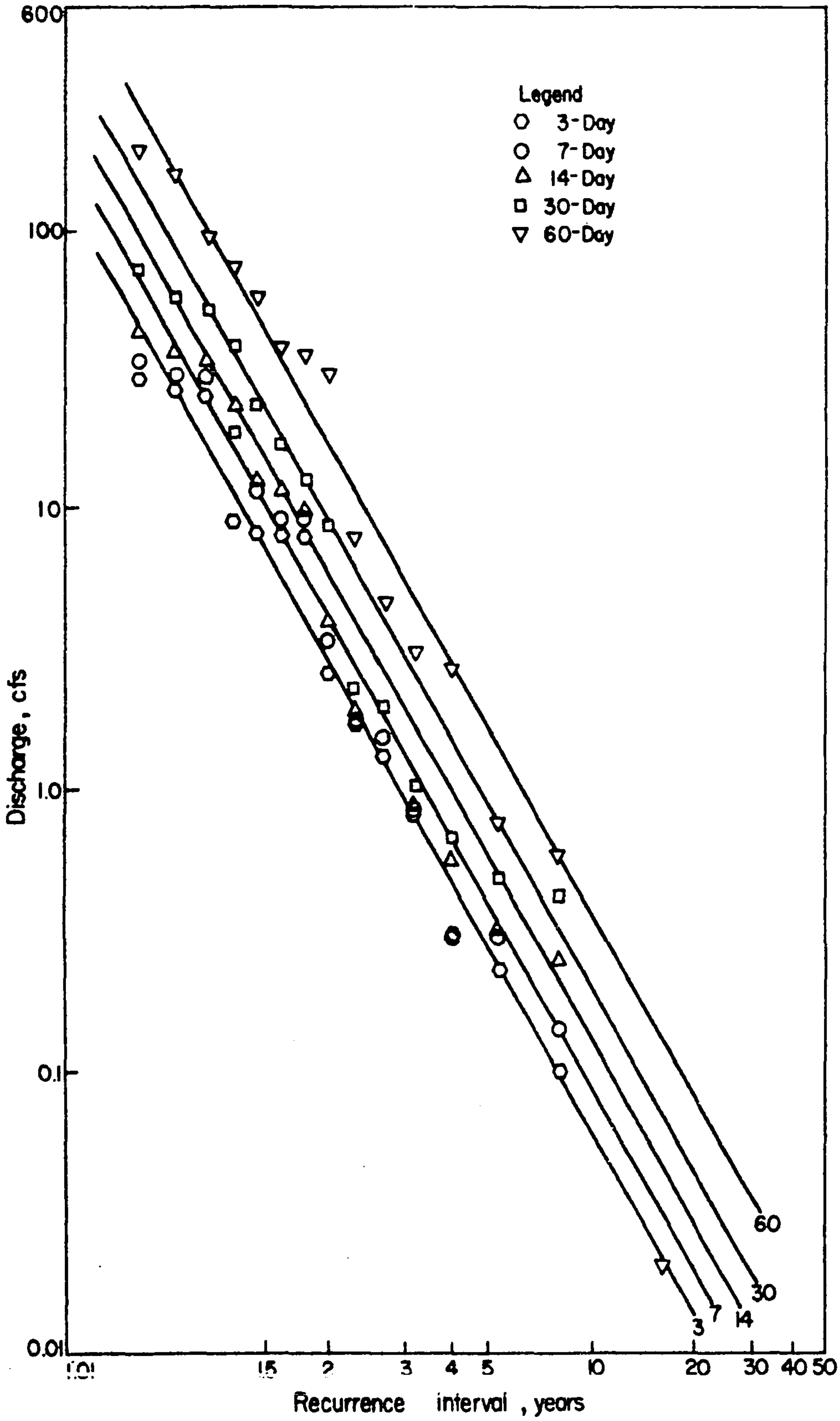
[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-12. Annual minimum low-flow discharges, Skunk River below Squaw Creek, summer season values, 1953-1967, for 30-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	01-31-53	1.96	5.17
2	1954	01-28-54	0.67	3.49
3	1955	11-16-54	23.13	25.83
4	1956	02-19-56	0.41	3.31
5	1957	02-07-57	0.0	3.04
6	1958	01-21-58	16.90	20.22
7	1959	02-16-59	12.53	15.92
8	1960	11-31-59	37.91	41.56
9	1961	11-28-60	69.83	73.50
10	1962	12-12-61	55.03	59.28
11	1963	01-04-63	49.83	54.17
12	1964	02-04-64	2.24	6.83
13	1965	01-31-65	1.02	5.65
14	1966	11-29-65	8.55	13.29
15	1967	01-30-67	0.48	5.17

[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

[b]Month-day-year designation, with September of a water year being month No. 1.


Legend
3-Day
7-Day
14-Day
30-Day
60-Day
Discharge, cfs
600
100
10
1.0
0.1
0.01
Recurrence interval, years
1.01
1.5
2
3
4
5
10
20
30
40
50
60
30
14
7
3

2. Winter season, annual minimum low-flow values for selected durations

Table A-13. Annual minimum low-flow discharges, Skunk River below Squaw Creek, winter season values, 1953-1967, for 3-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	04-01-53	2.03	3.99
2	1954	05-04-54	0.0	2.66
3	1955	05-15-55	22.0	25.11
4	1956	06-18-56	0.0	2.26
5	1957	04-17-57	2.20	5.52
6	1958	05-22-58	29.0	32.40
7	1959	05-22-59	0.20	3.36
8	1960	06-20-60	56.0	59.79
9	1961	05-05-61	3.80	7.26
10	1962	04-31-62	97.33	101.5
11	1963	05-03-63	3.20	7.17
12	1964	04-03-64	0.0	3.37
13	1965	05-04-65	0.0	4.51
14	1966	05-06-66	40.0	45.21
15	1967	06-08-67	0.0	4.86

[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-14. Annual minimum low-flow discharges, Skunk River below Squaw Creek, winter season values, 1953-1967, for 7-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	04-01-53	2.29	4.12
2	1954	05-04-54	0.0	2.58
3	1955	05-16-55	24.28	27.42
4	1956	06-18-56	0.0	2.71
5	1957	04-18-57	2.26	5.45
6	1958	05-22-58	29.0	32.28
7	1959	05-10-59	0.21	3.53
8	1960	06-21-60	56.57	60.50
9	1961	05-06-61	3.83	7.49
10	1962	05-01-62	98.28	102.6
11	1963	05-04-63	3.25	7.50
12	1964	04-03-64	0.01	3.34
13	1965	05-04-65	0.0	4.23
14	1966	05-07-66	41.14	46.50
15	1967	06-08-67	0.0	4.23

[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-15. Annual minimum low-flow discharges, Skunk River below Squaw Creek, winter season values, 1953-1967, for 14-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	04-07-53	2.51	4.57
2	1954	05-04-54	0.0	2.65
3	1955	05-16-55	26.64	29.74
4	1956	06-18-56	0.0	2.85
5	1957	04-19-57	2.66	5.83
6	1958	05-21-58	31.43	34.77
7	1959	05-10-59	0.26	3.60
8	1960	06-23-60	57.71	61.59
9	1961	05-08-61	4.33	8.11
10	1962	05-03-62	101.6	106.1
11	1963	05-05-63	3.52	7.76
12	1964	04-03-64	0.08	3.37
13	1965	04-21-65	0.0	4.05
14	1966	05-07-66	49.57	55.12
15	1967	06-08-67	0.0	4.12

[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

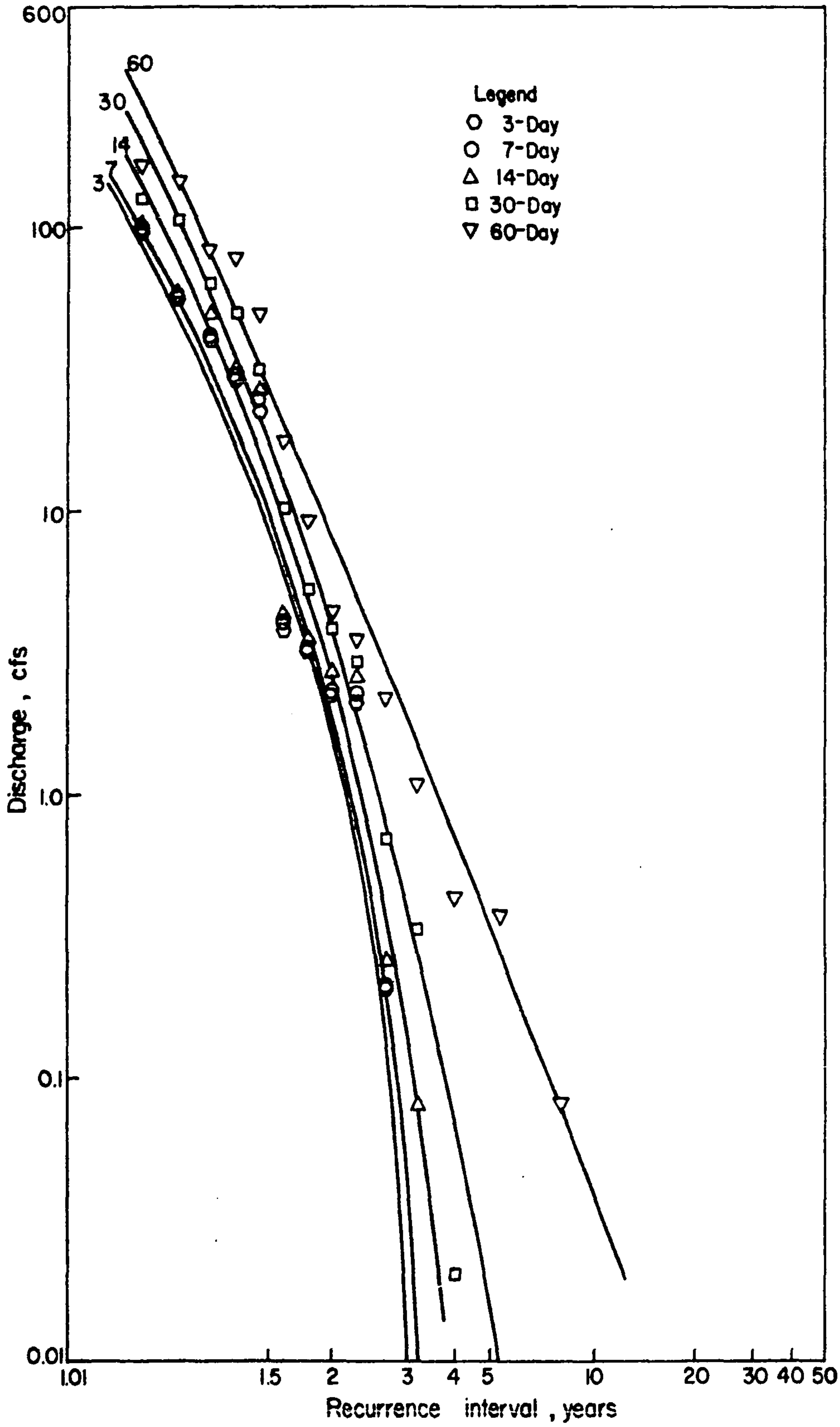
[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-16. Annual minimum low-flow discharges, Skunk River below Squaw Creek, winter season values, 1953-1967, for 30-day periods[a]

Line	Water year	Date ending[b]	Natural low-flow discharge, cfs	With effluent discharge added, cfs
1	1953	04-14-53	2.89	5.00
2	1954	05-04-54	0.02	2.51
3	1955	05-16-55	31.07	34.15
4	1956	06-18-56	0.0	2.87
5	1957	03-23-57	3.82	7.04
6	1958	05-22-58	49.17	52.62
7	1959	05-23-59	0.33	3.53
8	1960	06-26-60	62.56	66.22
9	1961	05-11-61	10.18	13.77
10	1962	05-05-62	126.4	131.0
11	1963	05-13-63	5.20	9.45
12	1964	04-09-64	0.69	4.44
13	1965	04-21-65	0.01	3.69
14	1966	05-07-66	105.6	111.2
15	1967	06-08-67	0.0	4.30

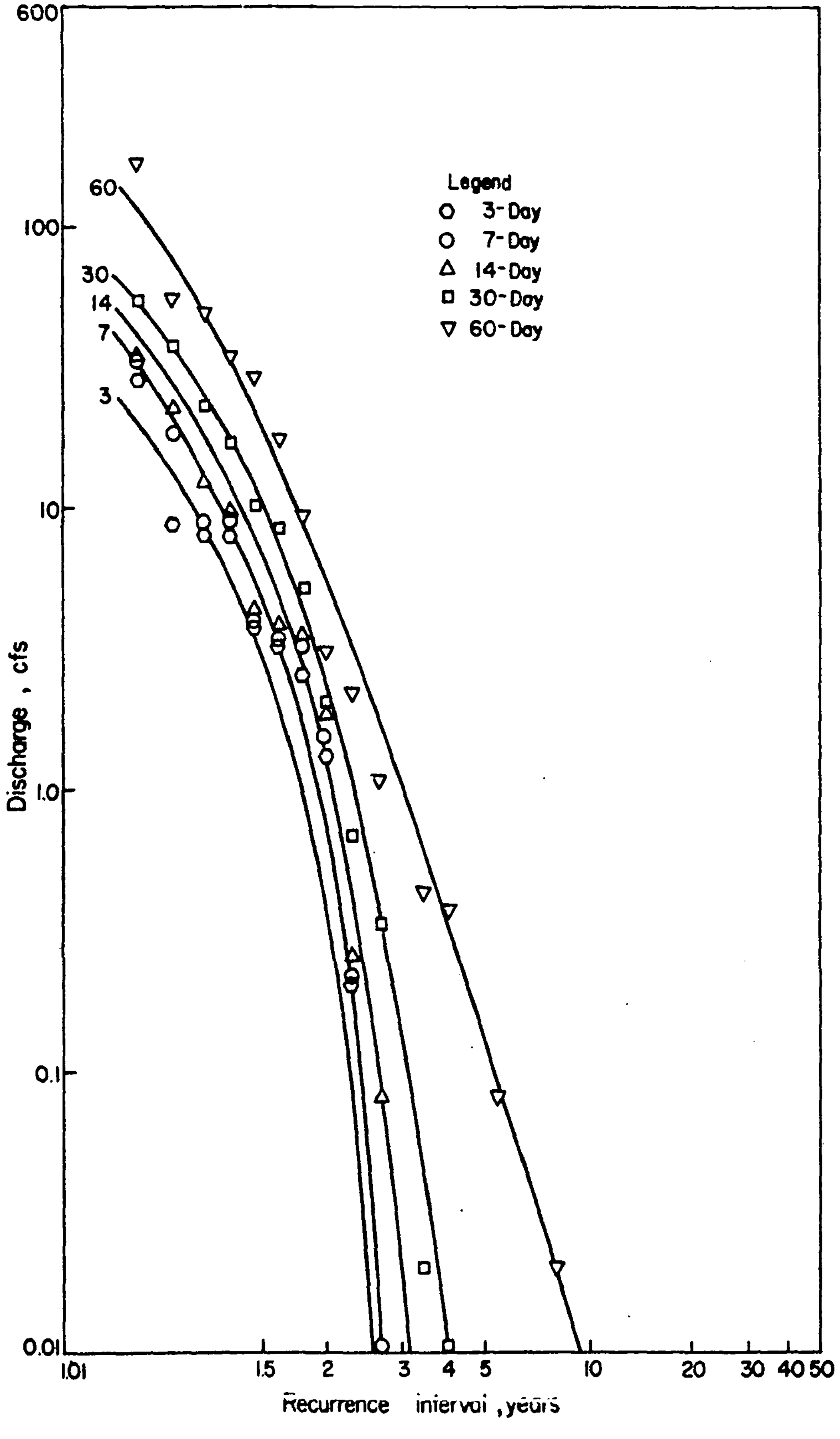
[a]Computer analysis of U.S.G.S. data; effluent discharge data from city of Ames.

[b]Month-day-year designation, with September of a water year being month No. 1.



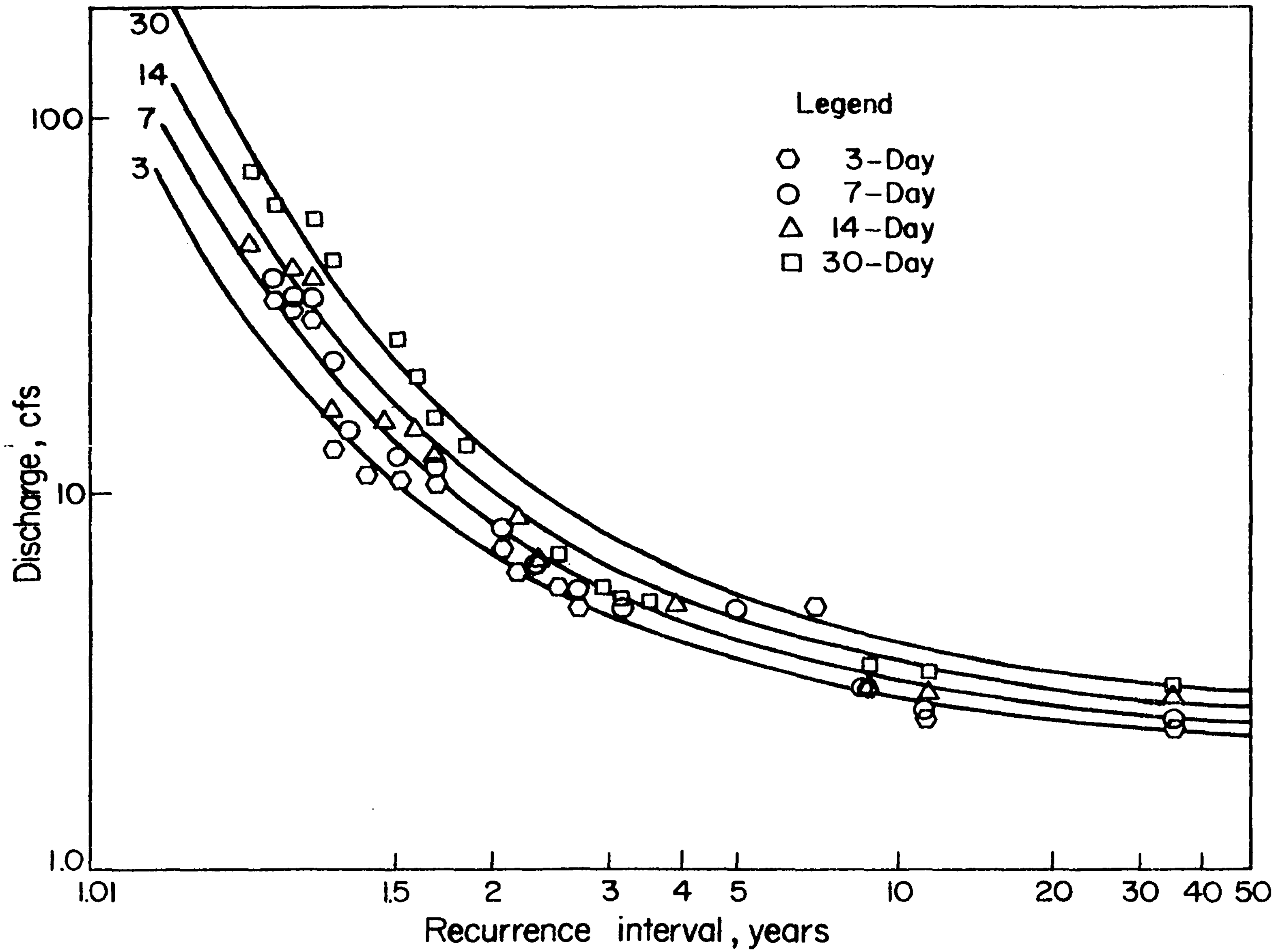
Legend
3-Day
7-Day
14-Day
30-Day
60-Day
60
30
14
7
3
Discharge, cfs
600
100
10
1.0
0.1
0.01
1.01
1.5
2
3
4
5
10
20
30
40
50
Recurrence interval, years

3. Annual low-flow frequency relationships, Skunk River below Squaw Creek


Discharge , cfs
600
100
10
1.0
0.1
0.01
Recurrence interval , years
1.01
1.5
2
3
4
5
10
20
30
40
50
Legend
3-Day
7-Day
14-Day
30-Day
60-Day
60
30
14
7
3

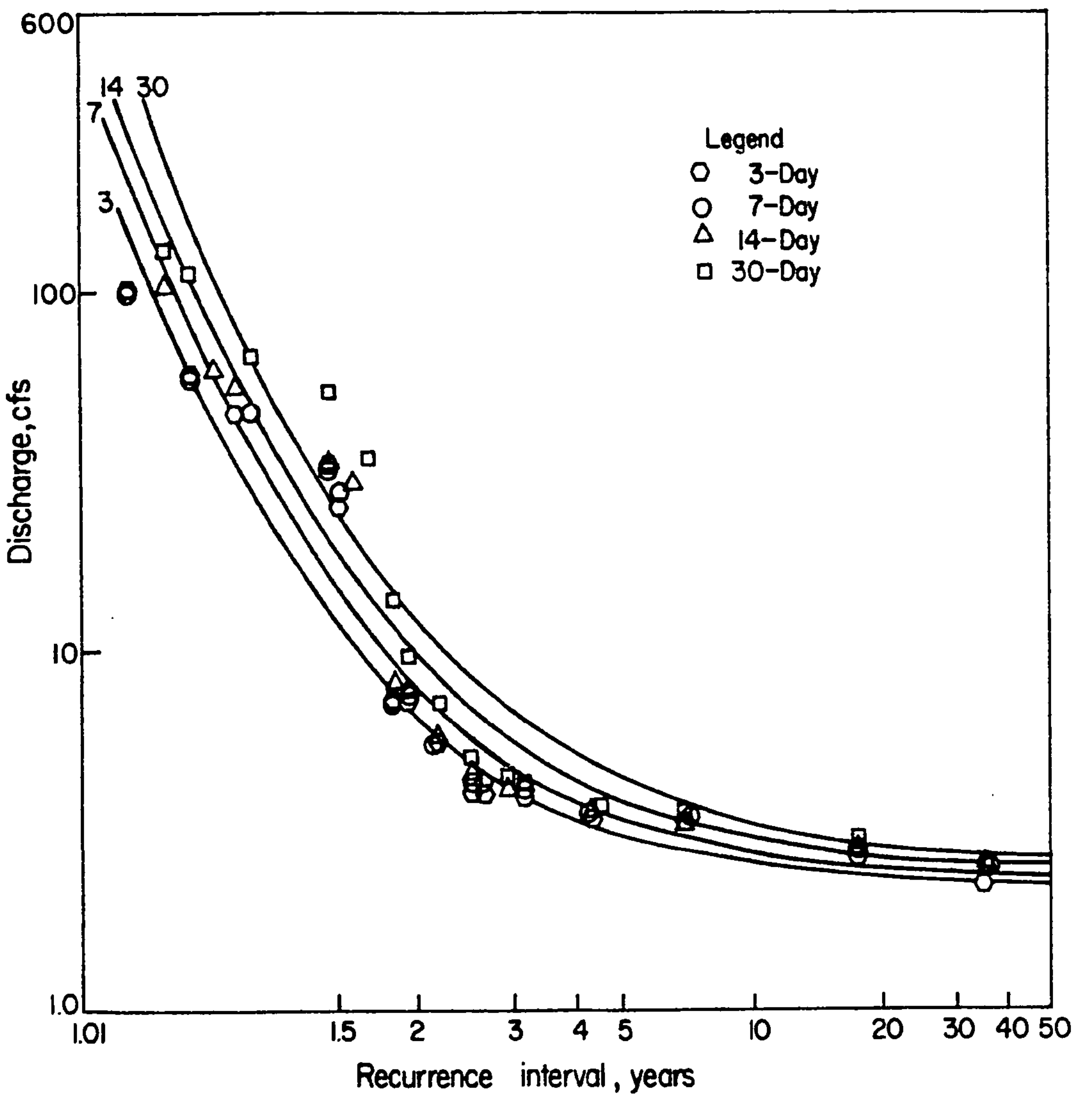
C. Low-Flow Discharge Data, Skunk River and Ames Effluent

1. Summer season, low-flow frequency relationships, Skunk River and Ames effluent



30
14
7
3
100
10
1.0
Discharge, cfs
Legend
3-Day
7-Day
14-Day
30-Day
1.01
1.5
2
3
4
5
10
20
30
40
50
Recurrence interval, years

2. Winter season, low-flow frequency relationships, Skunk River and Ames effluent



600
100
10
1.0
Discharge, cfs
1.01
1.5
2
3
4
5
10
20
30
40
50
Recurrence interval, years
7
14
30
3
Legend
3-Day
7-Day
14-Day
30-Day

D. Low-Flow Discharge Data, Skunk River near Oskaloosa, Iowa

1. Summer season, annual minimum low-flow values for selected durations

Table A-17. Annual minimum low-flow discharges, Skunk River at Oskaloosa, summer season values, 1949-1967, for 3-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	02-15-49	29.3	11	1959	02-14-59	78.7
2	1950	12-30-49	33.7	12	1960	12-25-59	97.7
3	1951	02-30-51	20.3	13	1961	12-16-60	186.7
4	1952	01-04-52	198.7	14	1962	12-11-61	154.7
5	1953	01-31-53	56.0	15	1963	12-29-62	129.3
6	1954	01-04-54	24.0	16	1964	01-15-64	68.3
7	1955	11-16-54	110.0	17	1965	02-23-65	52.0
8	1956	12-19-55	10.2	18	1966	11-24-65	92.7
9	1957	01-13-57	1.8	19	1967	01-02-67	50.3
10	1958	01-09-58	51.7				

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-18. Annual minimum low-flow discharges, Skunk River at Oskaloosa, summer season values, 1949-1967, for 7-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	02-15-49	30.9	11	1959	02-15-59	81.6
2	1950	12-30-49	35.7	12	1960	12-25-59	105.9
3	1951	12-23-50	34.4	13	1961	12-17-60	193.7
4	1952	01-04-52	208.9	14	1962	12-21-61	175.7
5	1953	02-04-53	57.1	15	1963	12-30-62	132.6
6	1954	01-06-54	24.4	16	1964	02-17-64	70.8
7	1955	11-16-54	114.6	17	1965	02-26-65	56.0
8	1956	12-20-55	11.5	18	1966	11-24-65	101.1
9	1957	01-13-57	2.0	19	1967	01-14-67	51.6
10	1958	01-10-58	53.6				

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-19. Annual minimum low-flow discharges, Skunk River at Oskaloosa, summer season values, 1949-1967, for 14-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	02-15-49	31.9	11	1959	02-16-59	84.6
2	1950	01-06-50	39.6	12	1960	12-25-59	108.2
3	1951	12-23-50	37.1	13	1961	12-22-60	208.8
4	1952	01-04-52	248.4	14	1962	12-11-61	191.4
5	1953	02-11-53	57.2	15	1963	01-01-63	141.7
6	1954	01-12-54	25.2	16	1964	01-18-64	73.8
7	1955	11-04-54	158.6	17	1965	02-27-65	62.6
8	1956	12-20-55	12.4	18	1966	11-24-65	104.1
9	1957	01-14-57	3.4	19	1967	01-14-67	54.1
10	1958	01-14-58	56.7				

[a]Computer analysis of U.S.G.S. data.

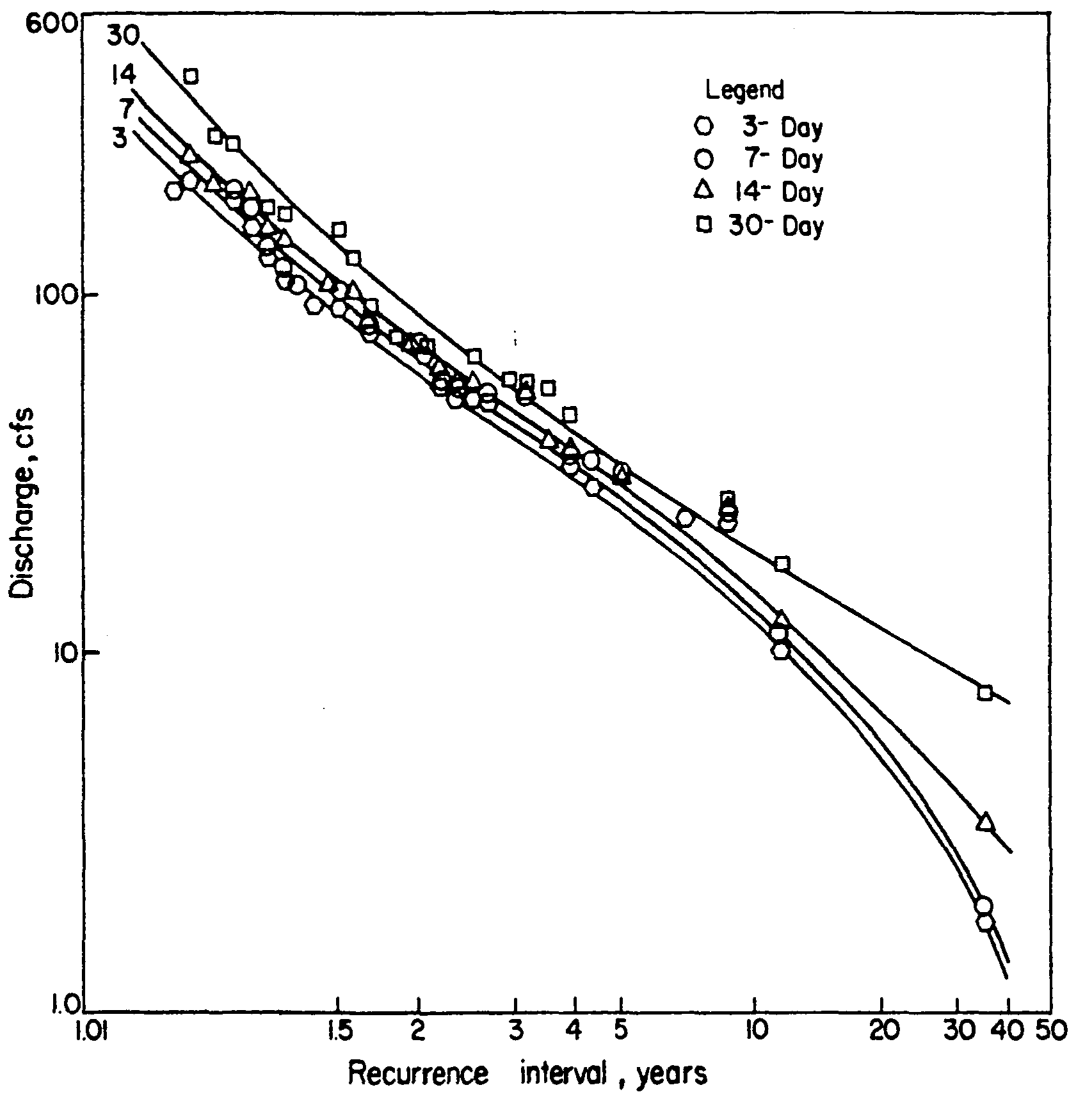
[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-20. Annual minimum low-flow discharges, Skunk River at Oskaloosa, summer season values, 1949-1967, for 30-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	02-15-49	32.1	11	1959	02-16-59	93.7
2	1950	02-19-50	56.1	12	1960	12-25-59	151.3
3	1951	12-23-50	46.0	13	1961	01-30-61	277.3
4	1952	01-04-52	405.2	14	1962	12-12-61	267.0
5	1953	02-14-53	58.1	15	1963	01-02-63	177.1
6	1954	01-24-54	26.3	16	1964	02-21-64	76.3
7	1955	11-17-54	170.6	17	1965	02-29-65	66.8
8	1956	12-27-55	17.6	18	1966	11-29-65	127.1
9	1957	01-25-57	7.7	19	1967	02-04-67	55.0
10	1958	01-23-58	63.3				

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.


600
100
10
1.0
Discharge, cfs
1.01
1.5
2
3
4
5
10
20
30
40
50
Recurrence interval, years
30
14
7
3
Legend
3- Day
7- Day
14- Day
30- Day

2. <u>Winter season, annual minimum low-flow values for selected durations</u>

Table A-21. Annual minimum low-flow discharges, Skunk River at Oskaloosa, winter season values, 1949-1967, for 3-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	03-10-49	42.3	11	1959	05-08-59	26.7
2	1950	04-30-50	28.0	12	1960	03-22-60	263.0
3	1951	04-15-51	7.6	13	1961	05-01-61	74.7
4	1952	04-13-52	170.0	14	1962	05-03-62	440.0
5	1953	04-08-53	72.3	15	1963	03-13-63	47.0
6	1954	05-02-54	14.0	16	1964	04-02-64	25.0
7	1955	05-17-55	88.0	17	1965	03-02-65	33.0
8	1956	04-27-56	4.4	18	1966	05-06-66	228.3
9	1957	04-20-57	5.1	19	1967	04-20-67	22.7
10	1958	05-22-58	60.0				

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-22. Annual minimum low-flow discharges, Skunk River at Oskaloosa, winter season values, 1949-1967, for 7-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	03-11-49	51.6	11	1959	05-08-59	26.9
2	1950	05-02-50	29.0	12	1960	03-25-60	268.7
3	1951	04-15-51	7.6	13	1961	05-03-61	79.8
4	1952	04-14-52	174.3	14	1962	05-03-62	448.6
5	1953	04-11-53	74.7	15	1963	03-16-63	50.7
6	1954	05-02-54	14.0	16	1964	04-03-64	25.9
7	1955	05-17-55	91.1	17	1965	03-06-65	36.6
8	1956	04-30-56	4.5	18	1966	05-07-66	243.6
9	1957	04-20-57	5.2	19	1967	04-22-67	25.7
10	1958	05-22-58	60.0				

[a]Computer analysis of U.S.G.S. data.

[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-23. Annual minimum low-flow discharges, Skunk River at Oskaloosa, winter season values, 1949-1967, for 14-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	03-12-49	67.0	11	1959	05-08-59	27.2
2	1950	05-05-50	33.2	12	1960	03-26-60	281.9
3	1951	04-15-51	7.9	13	1961	05-09-61	77.9
4	1952	04-15-52	183.6	14	1962	05-04-62	467.1
5	1953	04-13-53	86.9	15	1963	03-21-63	64.5
6	1954	05-02-54	14.0	16	1964	04-04-64	26.8
7	1955	05-18-55	98.7	17	1965	03-31-65	40.7
8	1956	05-01-56	4.7	18	1966	05-07-66	281.1
9	1957	04-20-57	5.9	19	1967	04-22-67	28.6
10	1958	05-22-58	68.9				

[a]Computer analysis of U.S.G.S. data.

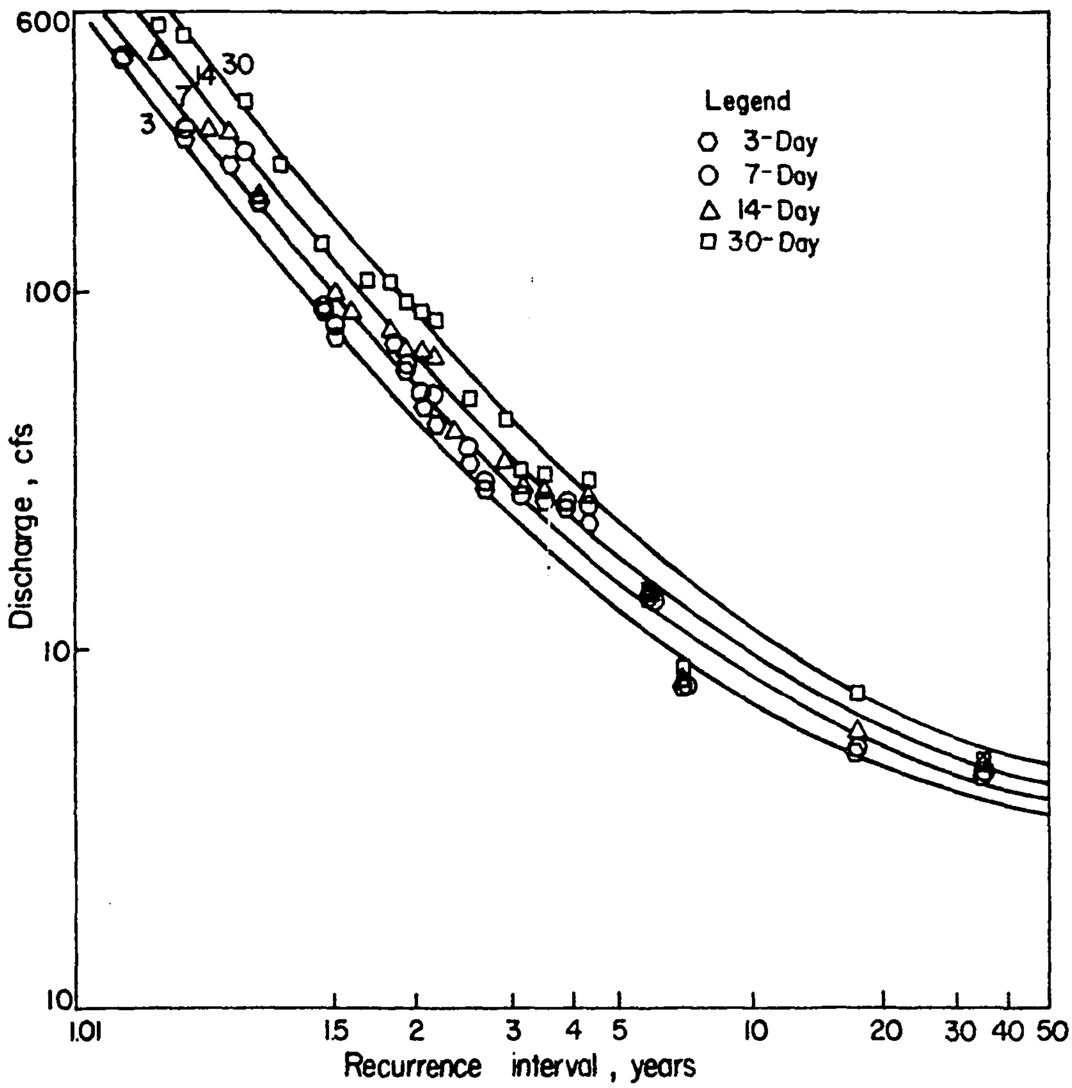
[b]Month-day-year designation, with September of a water year being month No. 1.

Table A-24. Annual minimum low-flow discharges, Skunk River at Oskaloosa, winter season values, 1949-1967, for 30-day periods[a]

Line	Water year	Date ending[b]	Low-flow discharge, cfs	Line	Water year	Date ending[b]	Low-flow discharge, cfs
1	1949	03-28-49	86.5	11	1959	05-09-59	29.6
2	1950	03-19-50	50.0	12	1960	03-26-60	338.5
3	1951	04-18-51	8.8	13	1961	05-11-61	93.1
4	1952	04-16-52	225.7	14	1962	05-04-62	548.7
5	1953	04-13-53	109.2	15	1963	05-06-63	82.9
6	1954	05-04-54	14.5	16	1964	04-13-64	30.8
7	1955	05-18-55	132.9	17	1965	03-29-65	44.0
8	1956	05-12-56	4.9	18	1966	06-21-66	518.6
9	1957	04-20-57	7.5	19	1967	04-22-67	31.7
10	1958	05-22-58	105.3				

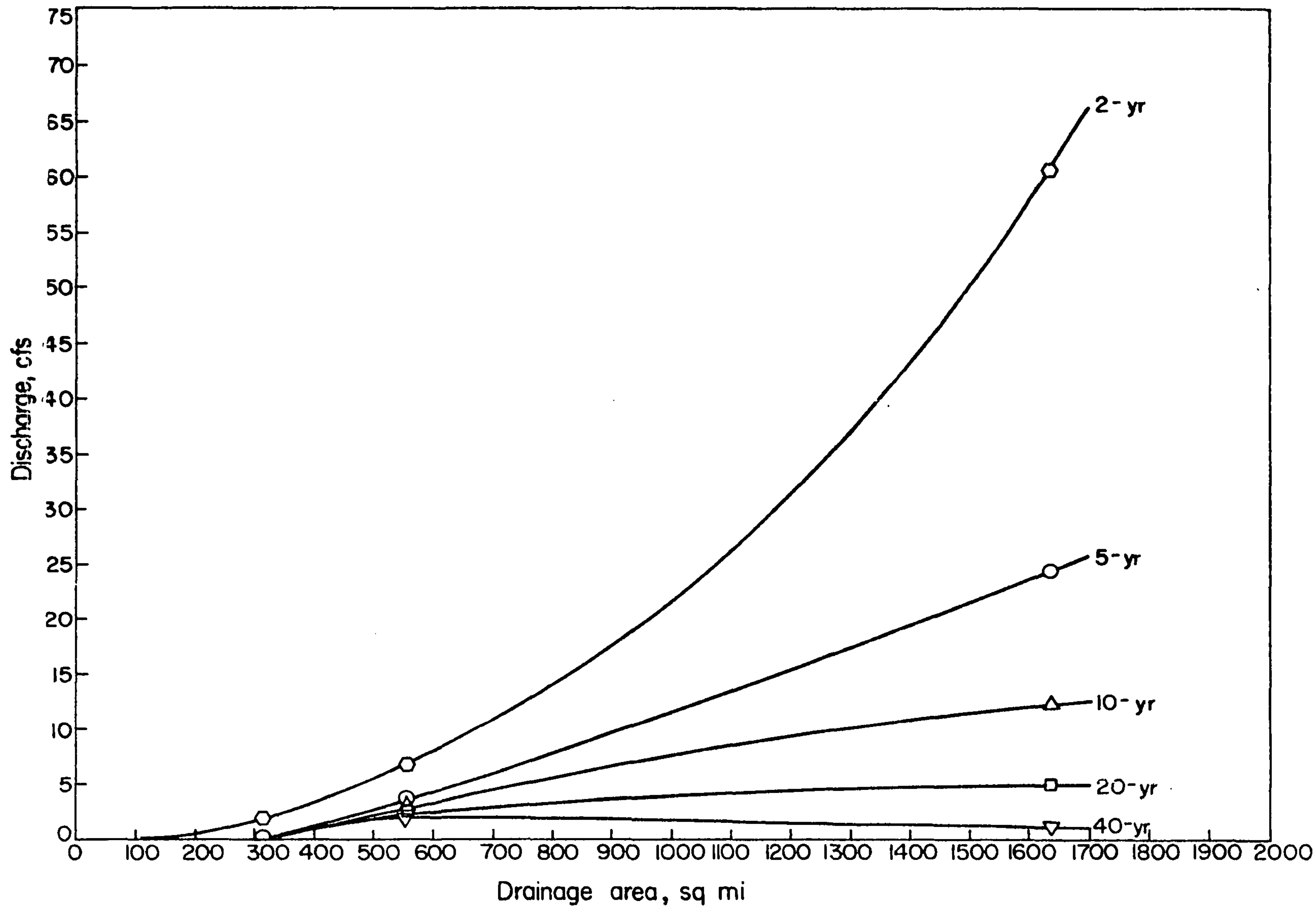
[a]Computer analysis of U.S.G.S. data.

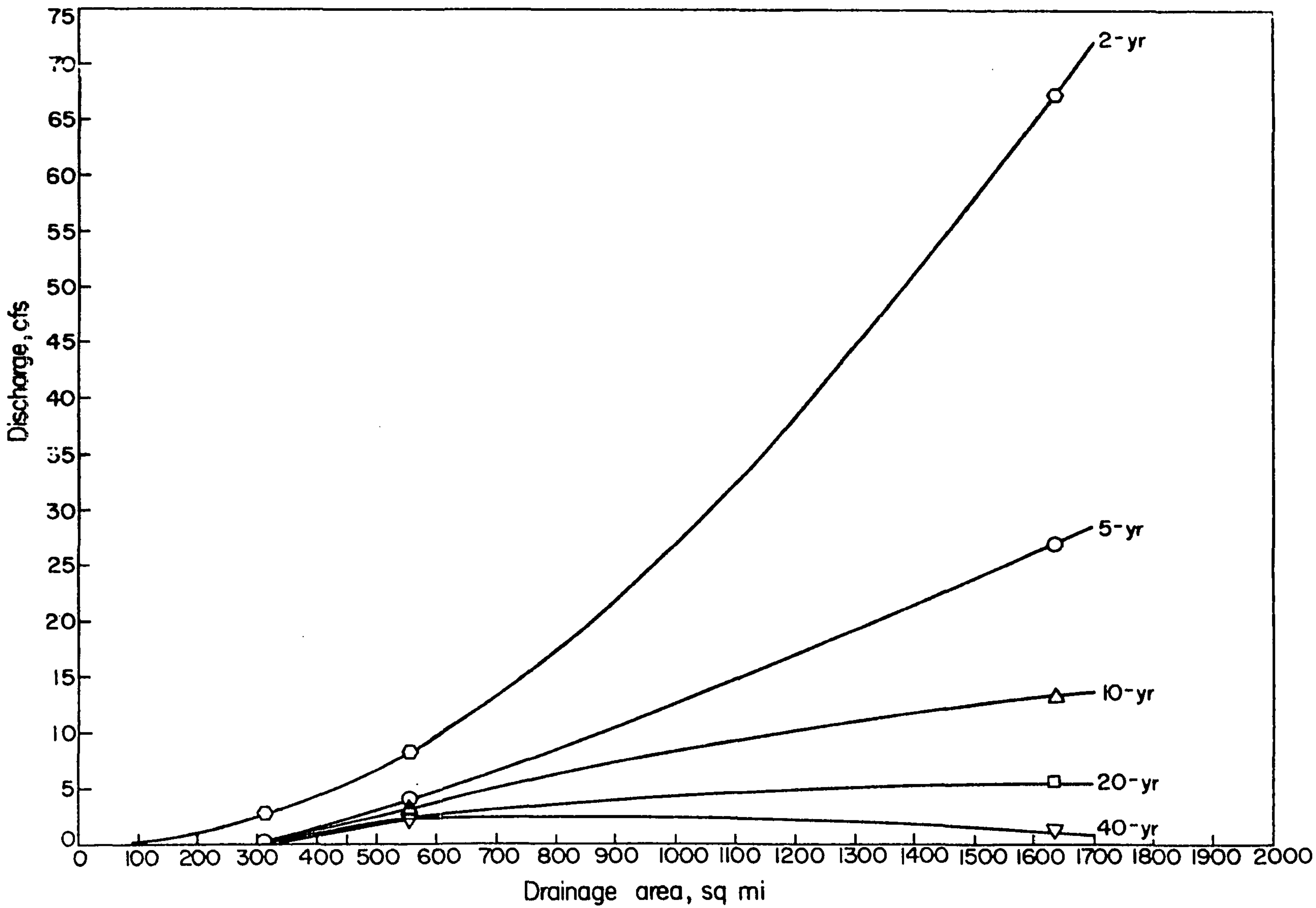
[b]Month-day-year designation, with September of a water year being month No. 1.

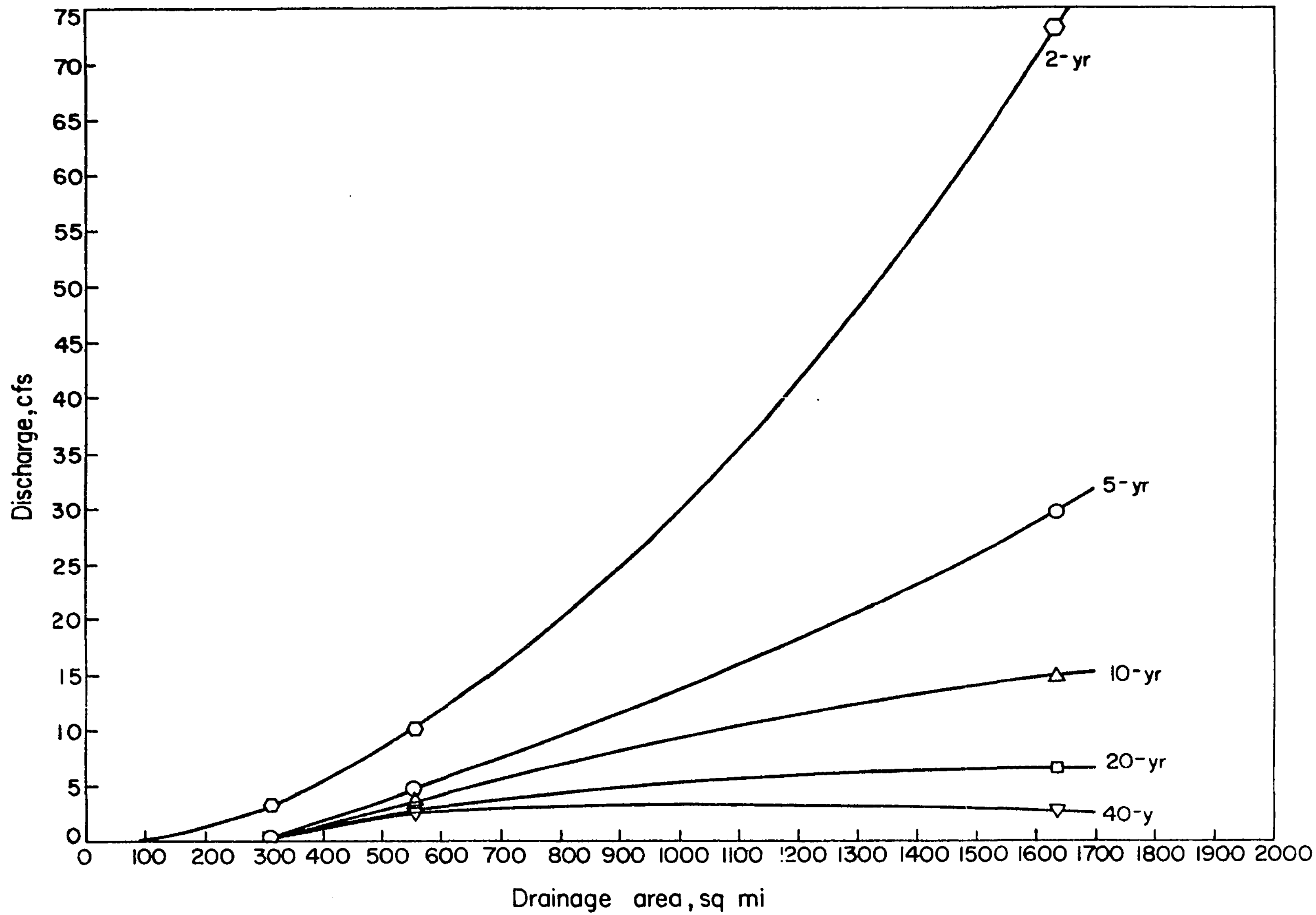

600
100
10
10
Discharge , cfs
1.01
1.5
2
3
4
5
10
20
30
40
50
Recurrence interval , years
3
7
14
30
Legend
3-Day
7-Day
14-Day
30-Day

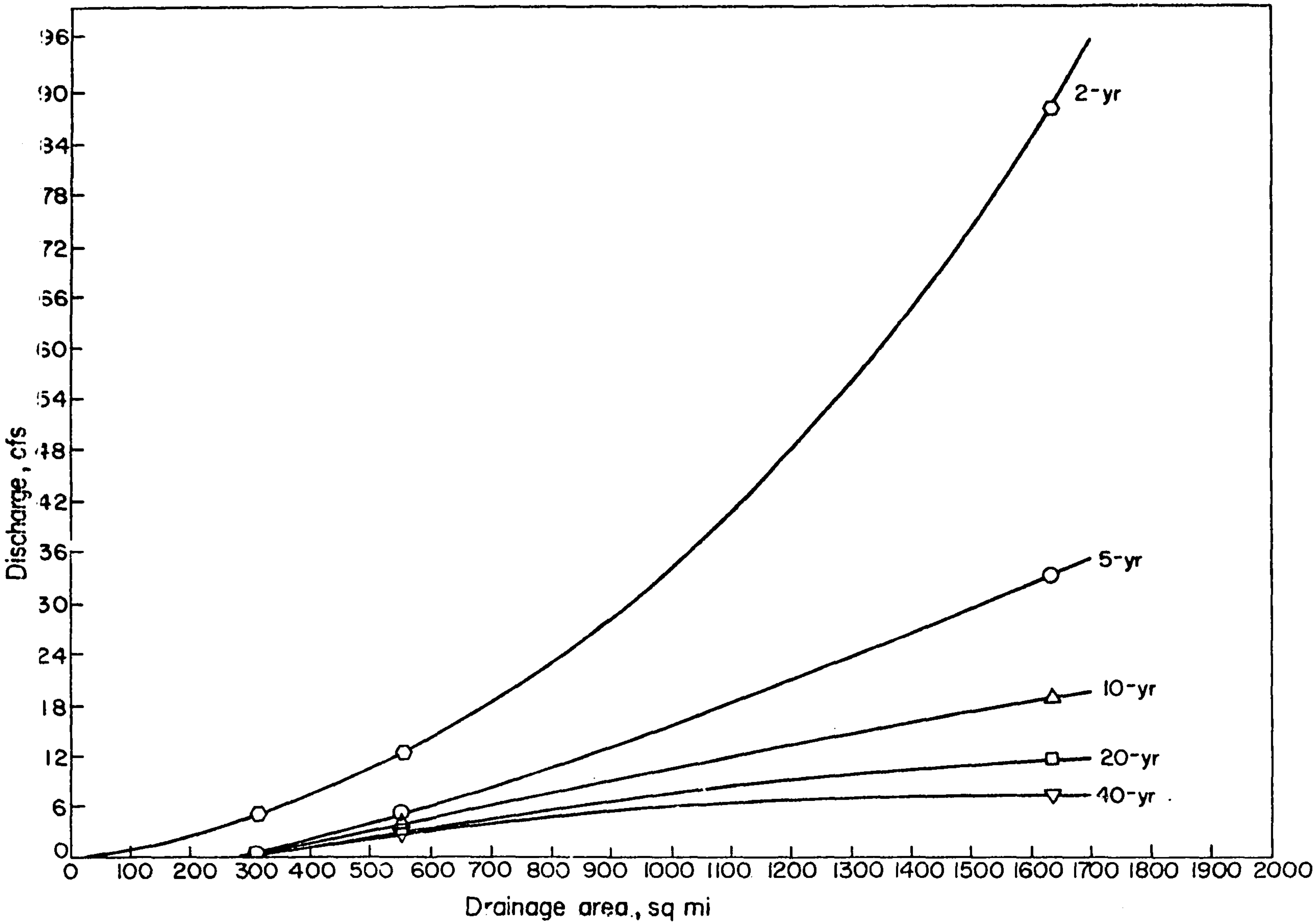
E. Regional Magnitude and Frequency of Low Flows, Upper Skunk River Basin

1. Regional relationships, summer season, for periods of 3, 7, 14, and 30 days


Discharge, cfs
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
2- yr
5- yr
10- yr
20- yr
40- yr
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Drainage area, sq mi

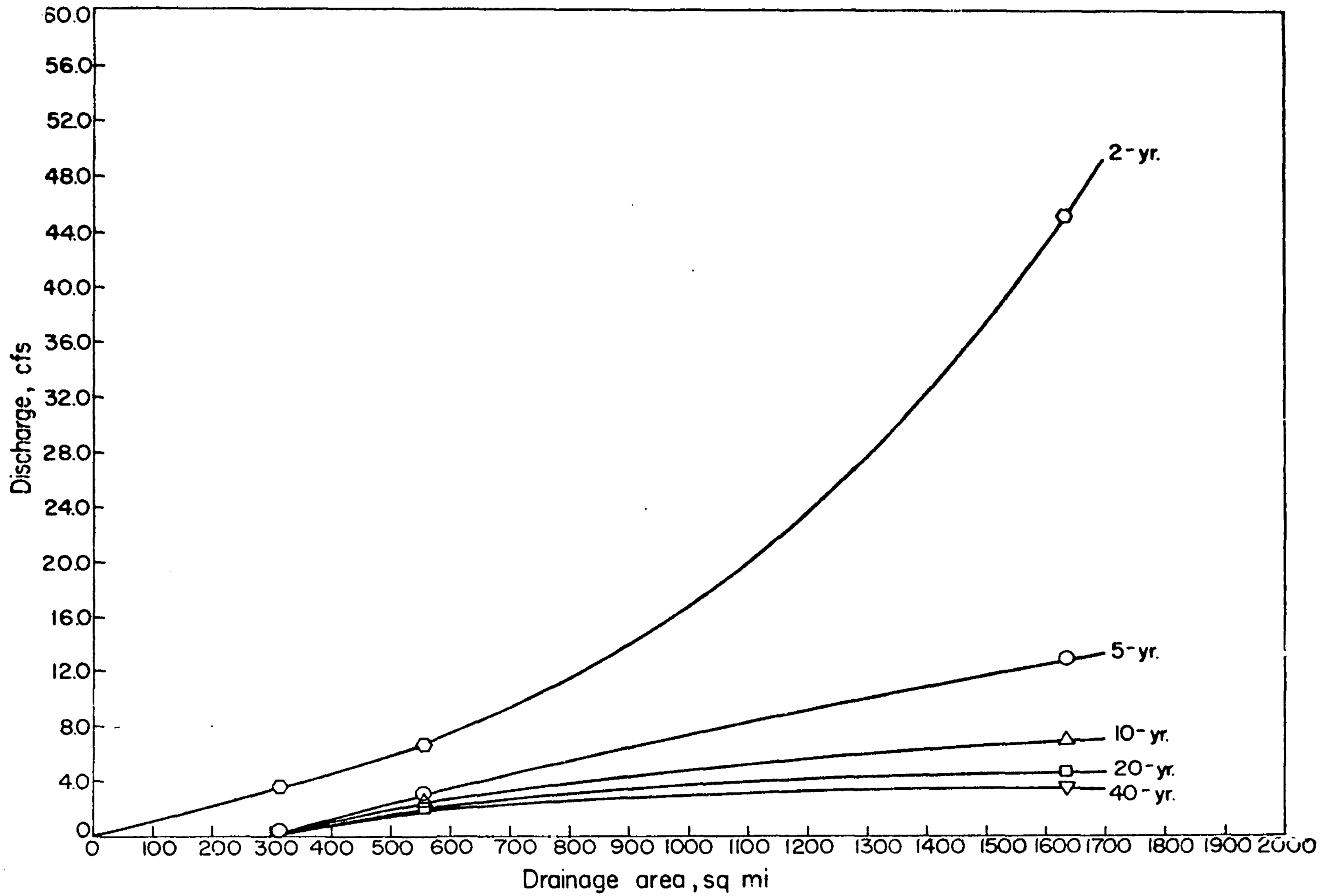

Discharge, cfs
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Drainage area, sq mi
2-yr
5-yr
10-yr
20-yr
40-yr


Discharge, cfs
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
Drainage area, sq mi
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2-yr
5-yr
10-yr
20-yr
40-y

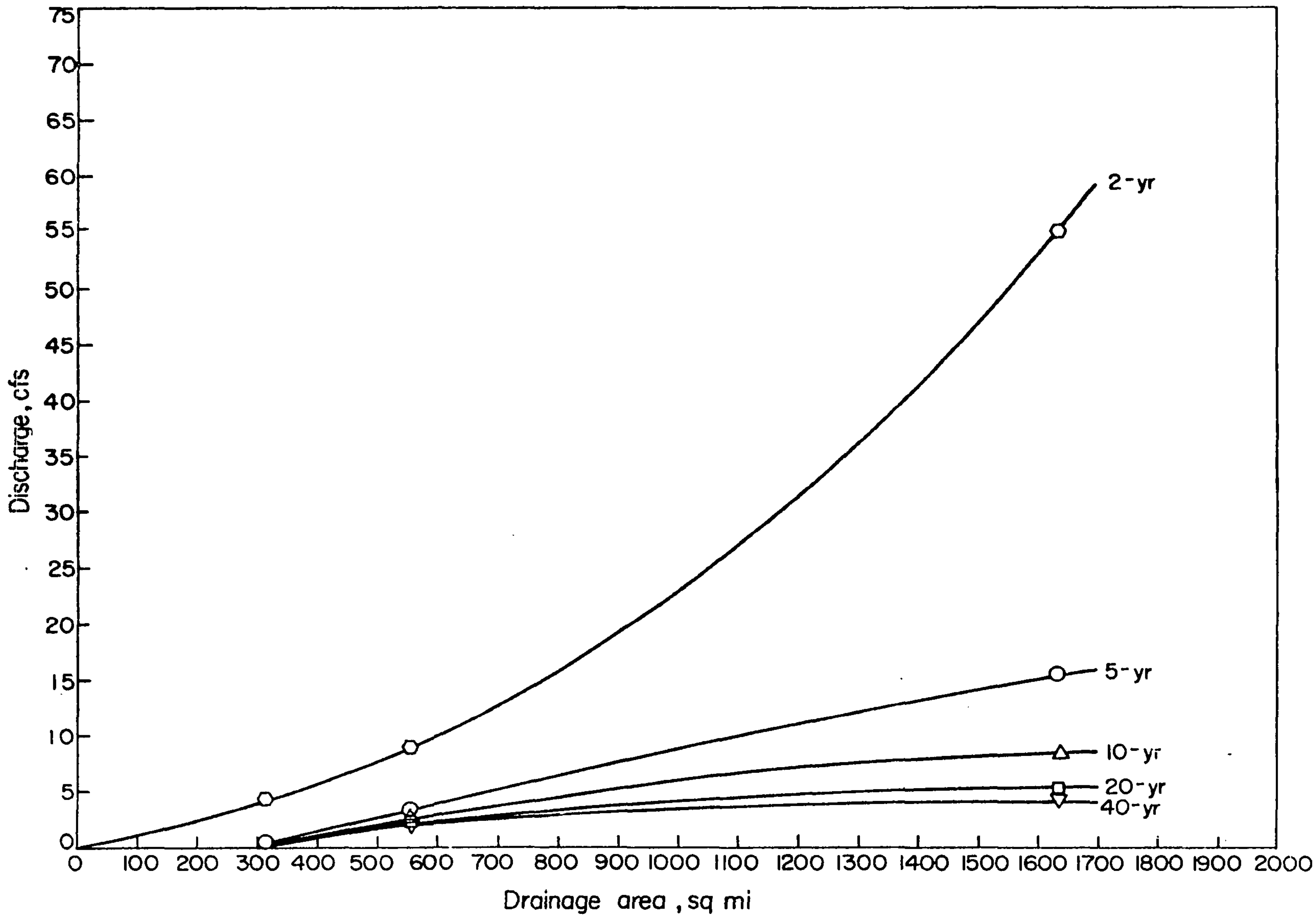


Discharge, cfs
96
90
84
78
72
66
60
54
48
42
36
30
24
18
12
6
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Drainage area., sq mi
2-yr
5-yr
10-yr
20-yr
40-yr

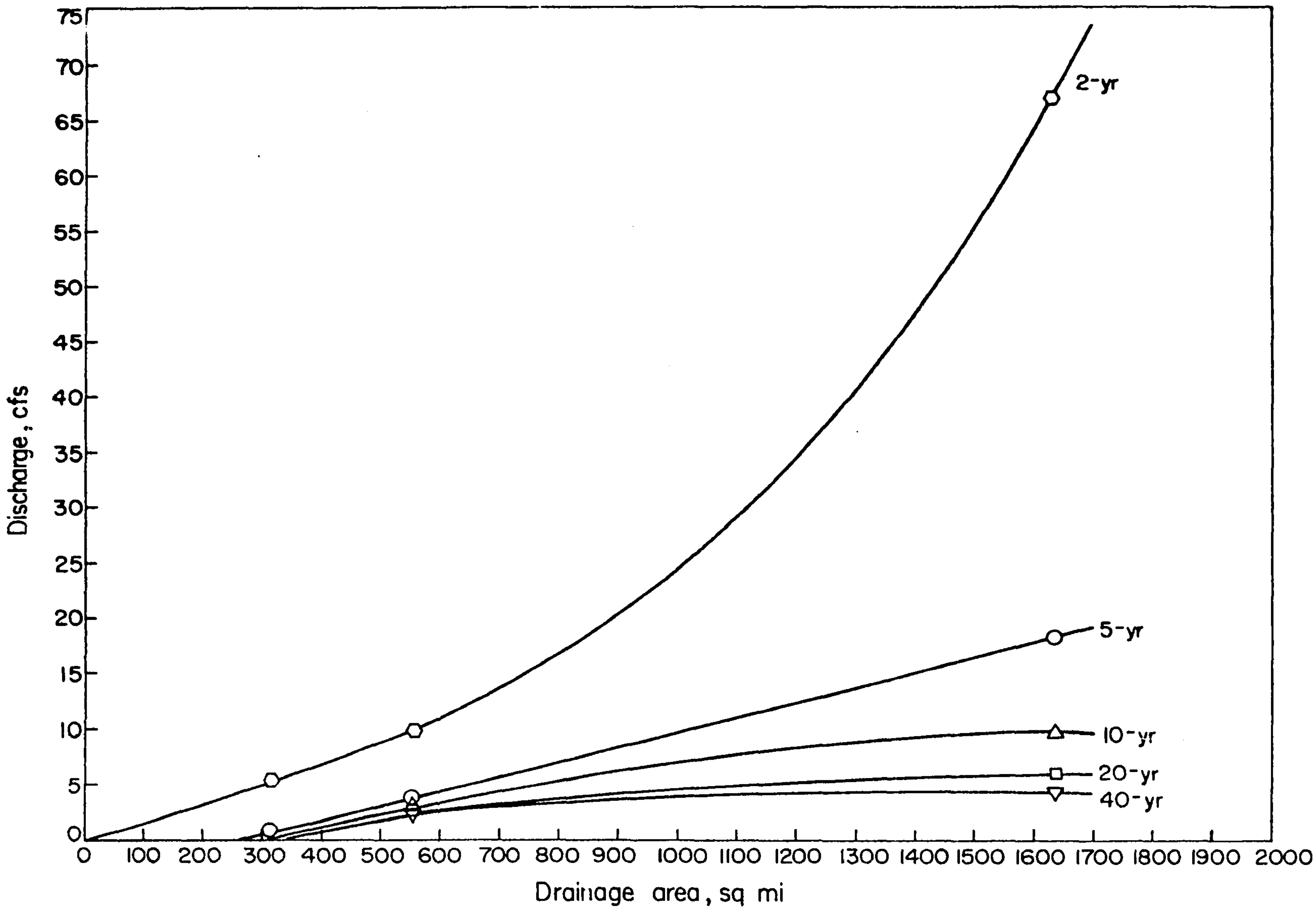
2. Regional relationships, winter season, for 3-, 7-, 14-, and 30-day periods



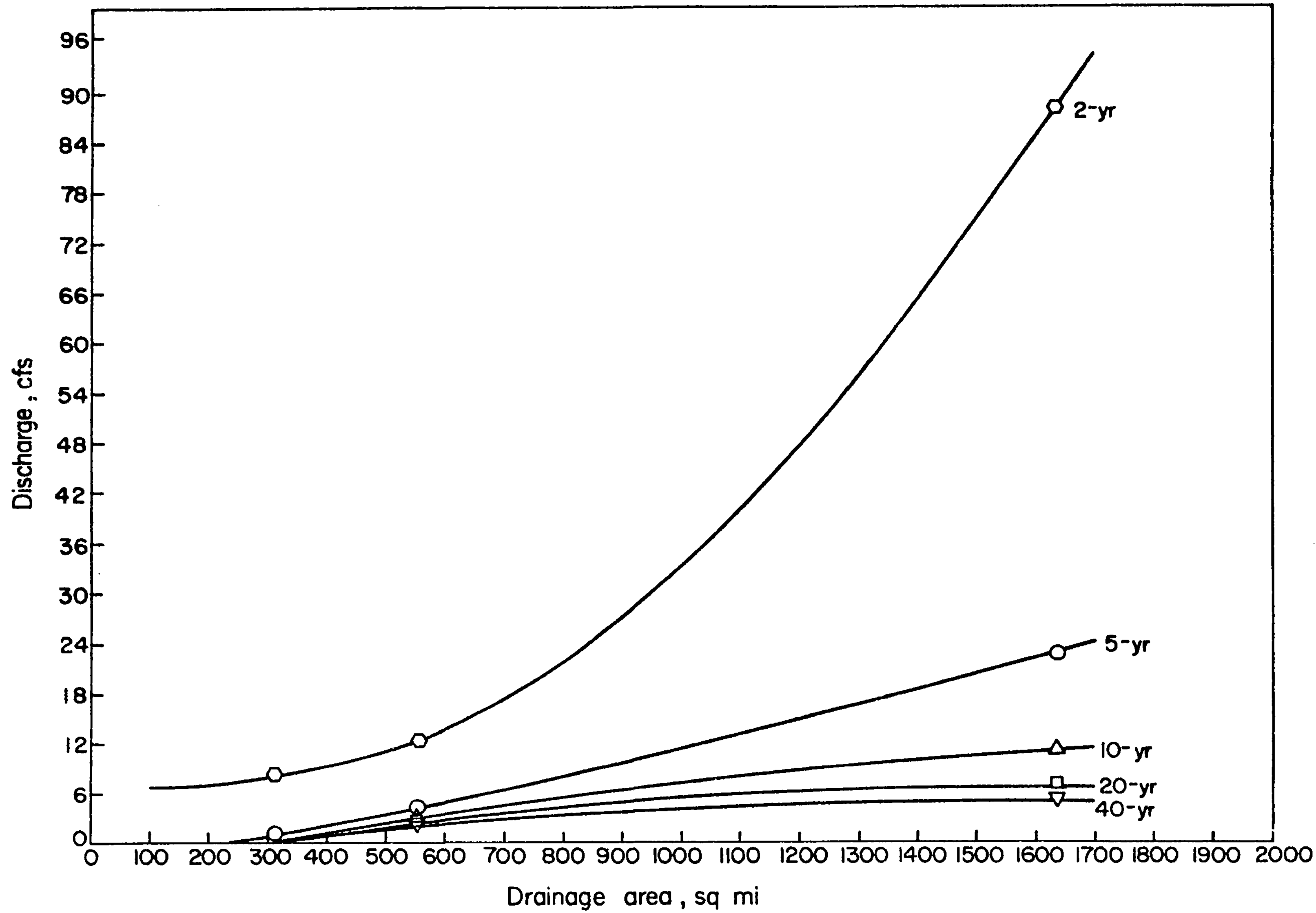
Discharge, cfs
60.0
56.0
52.0
48.0
44.0
40.0
36.0
32.0
28.0
24.0
20.0
16.0
12.0
8.0
4.0
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Drainage area, sq mi
2-yr.
5-yr.
10-yr.
20-yr.
40-yr.



75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Discharge, cfs
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Drainage area, sq mi
2-yr
5-yr
10-yr
20-yr
40-yr

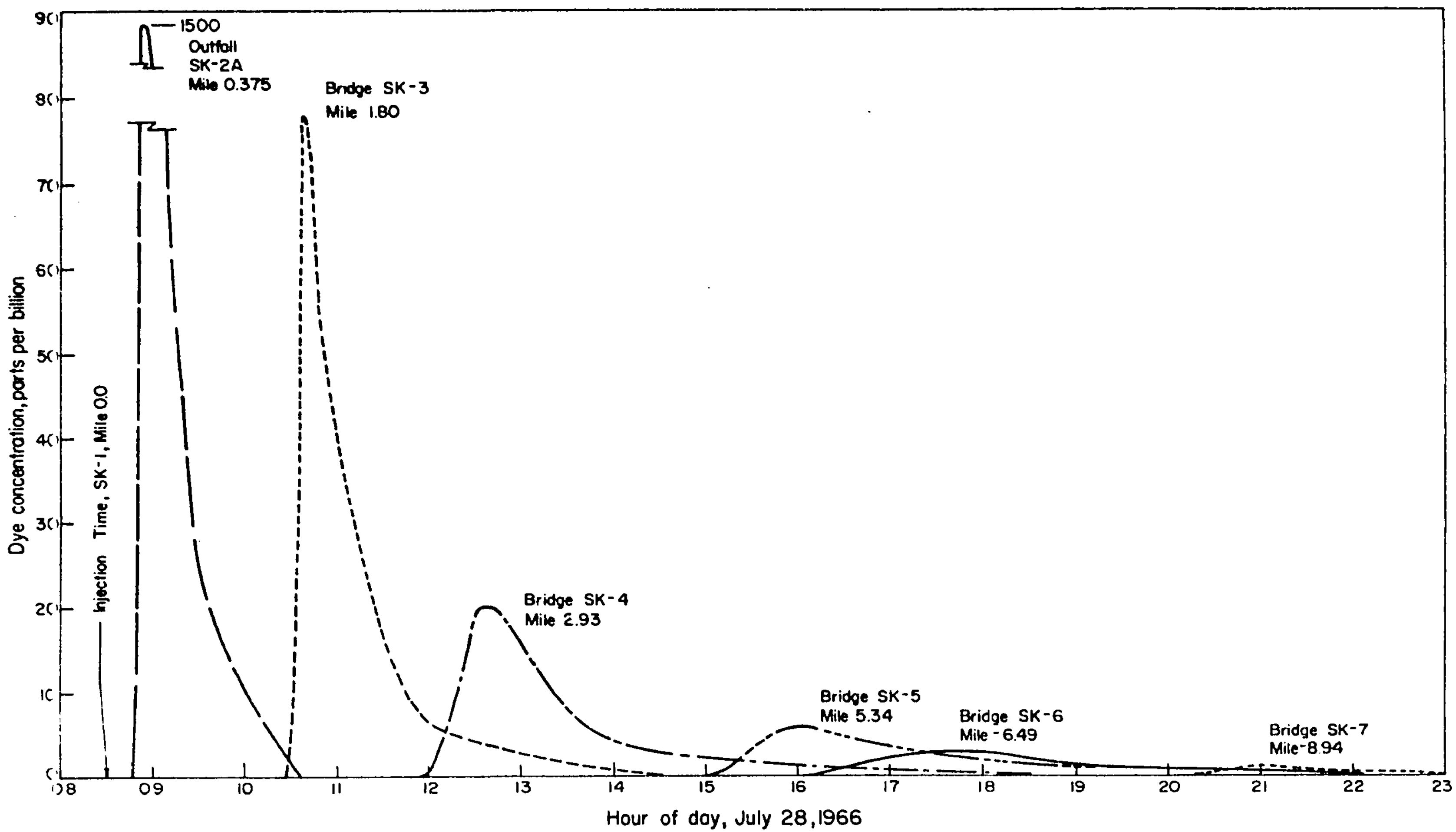


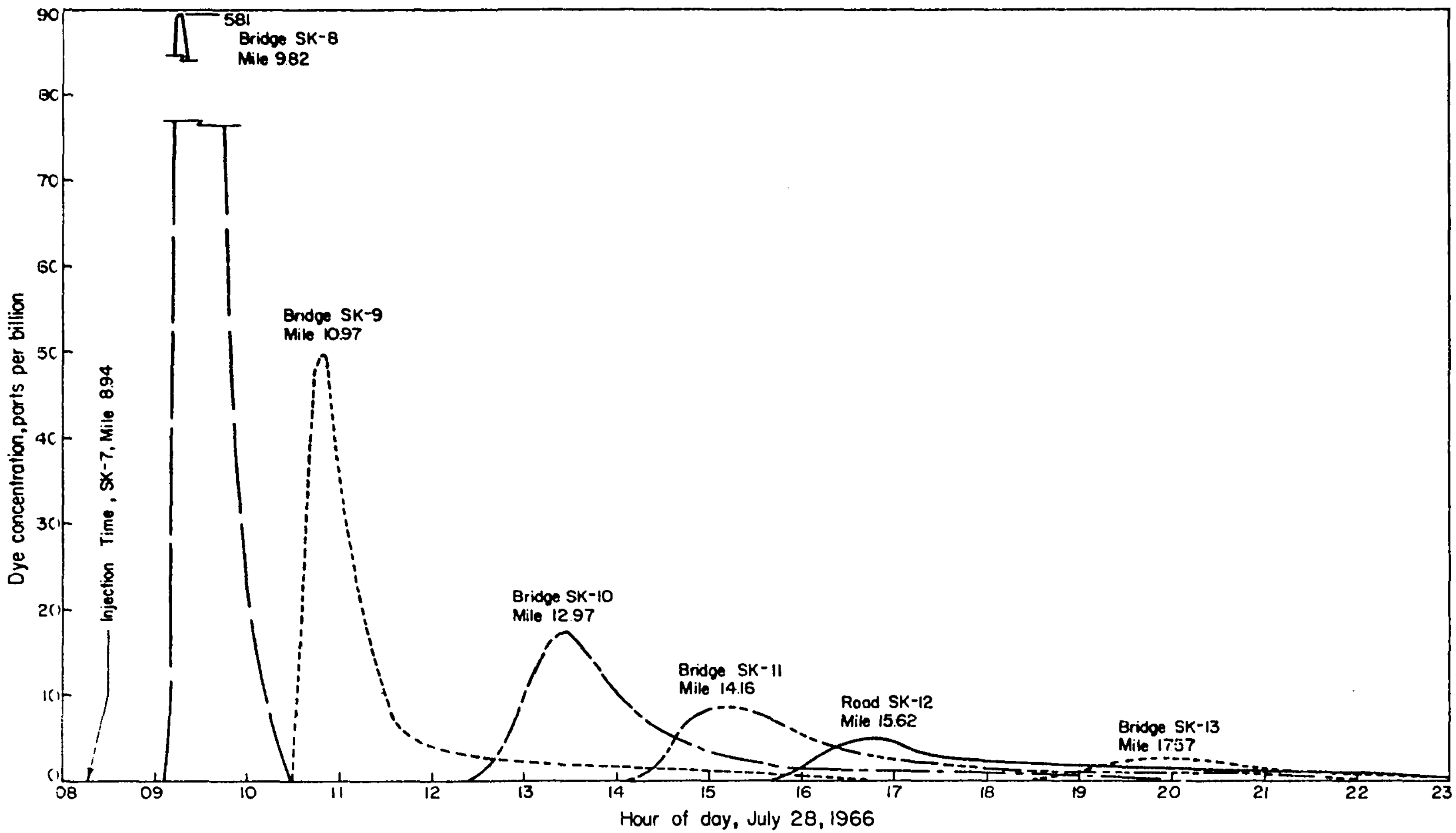
Discharge, cfs
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
Drainage area, sq mi
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2-yr
5-yr
10-yr
20-yr
40-yr


Discharge, cfs
96
90
84
78
72
66
60
54
48
42
36
30
24
18
12
6
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Drainage area, sq mi
2-yr
5-yr
10-yr
20-yr
40-yr

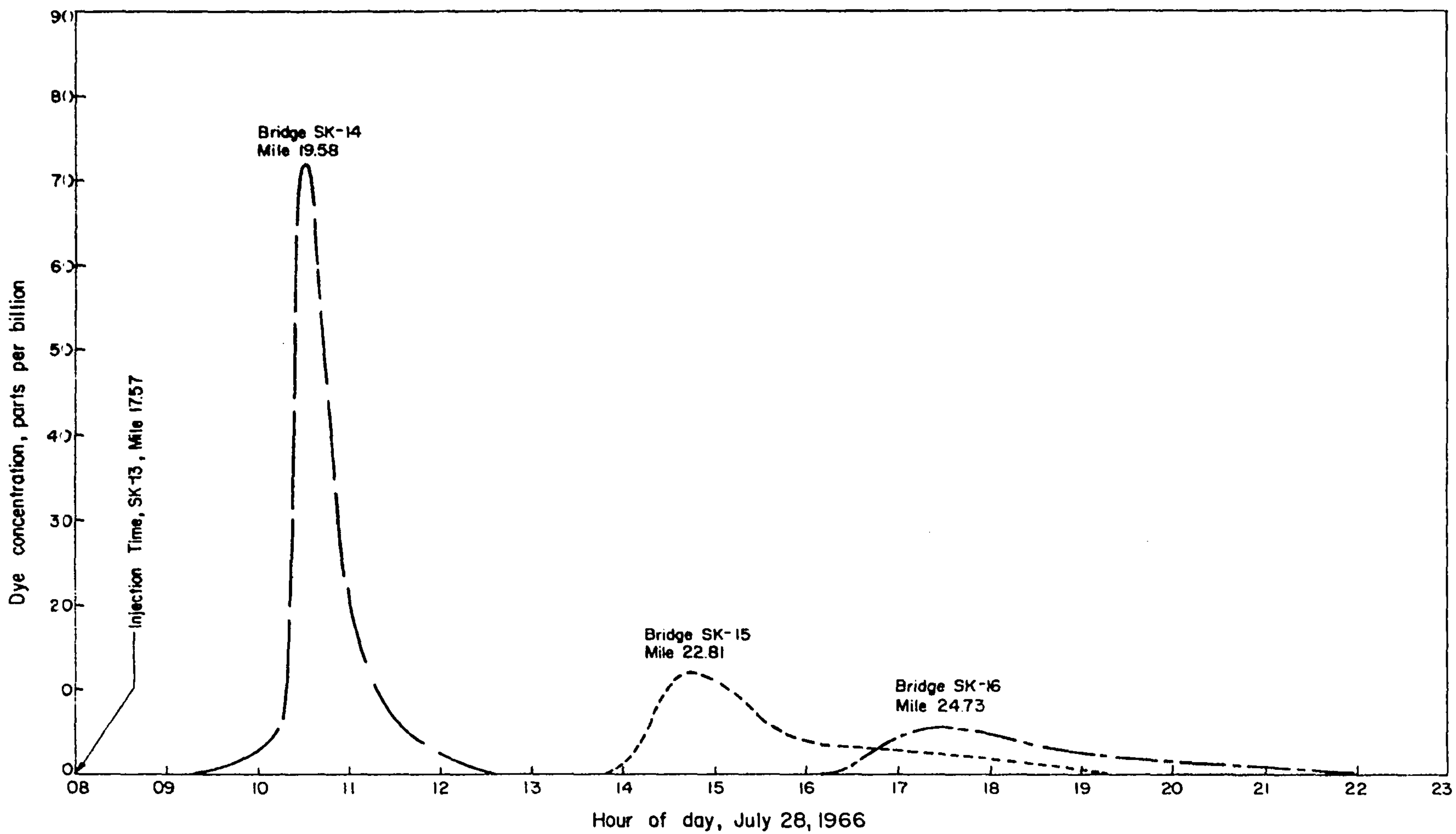
XIX. APPENDIX B

A. Concentration Hydrographs for Dye Tracer Study of July 28, 1966


1500
Outfall
SK-2A
Mile 0.375
Bridge SK-3
Mile 1.80
Bridge SK-4
Mile 2.93
Bridge SK-5
Mile 5.34
Bridge SK-6
Mile - 6.49
Bridge SK-7
Mile-8.94
Injection Time, SK-1, Mile 0.0
Dye concentration, parts per billion
90
80
70
60
50
40
30
20
10
0
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Hour of day, July 28, 1966

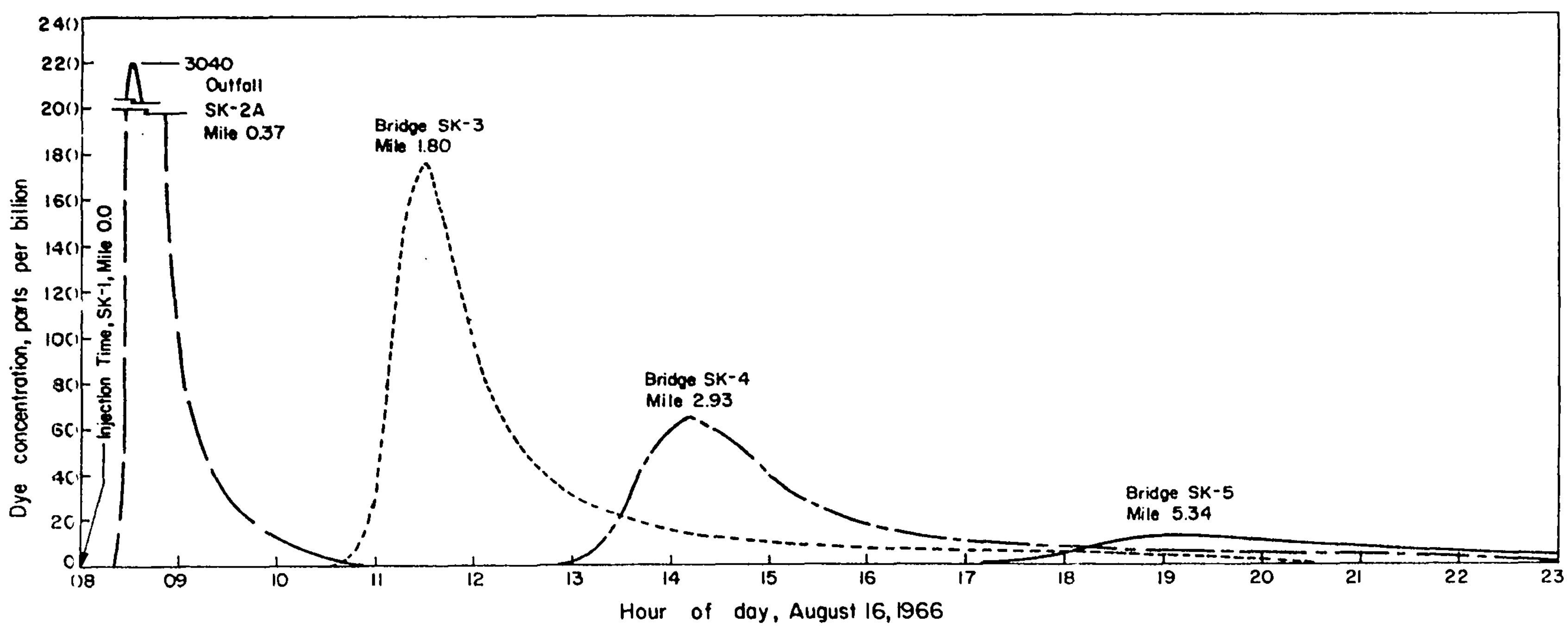


581
Bridge SK-8
Mile 9.82
Bridge SK-9
Mile 10.97
Injection Time, SK-7, Mile 8.94
Bridge SK-10
Mile 12.97
Bridge SK-11
Mile 14.16
Road SK-12
Mile 15.62
Bridge SK-13
Mile 17.57
Dye concentration, parts per billion
Hour of day, July 28, 1966
0
10
20
30
40
50
60
70
80
90
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23

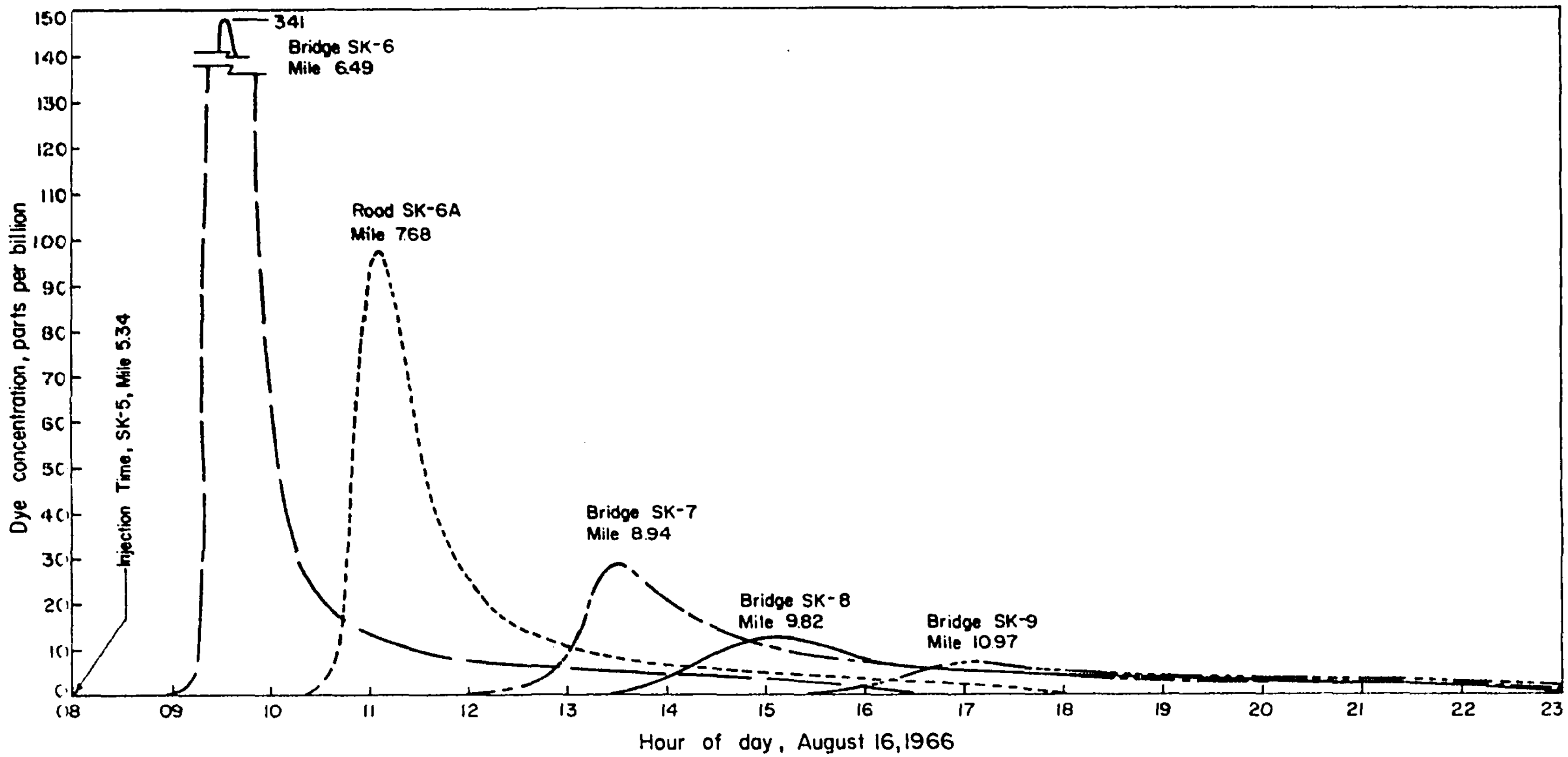


Dye concentration, parts per billion
Injection Time, SK-13, Mile 17.57
Bridge SK-14
Mile 19.58
Bridge SK-15
Mile 22.81
Bridge SK-16
Mile 24.73
Hour of day, July 28, 1966

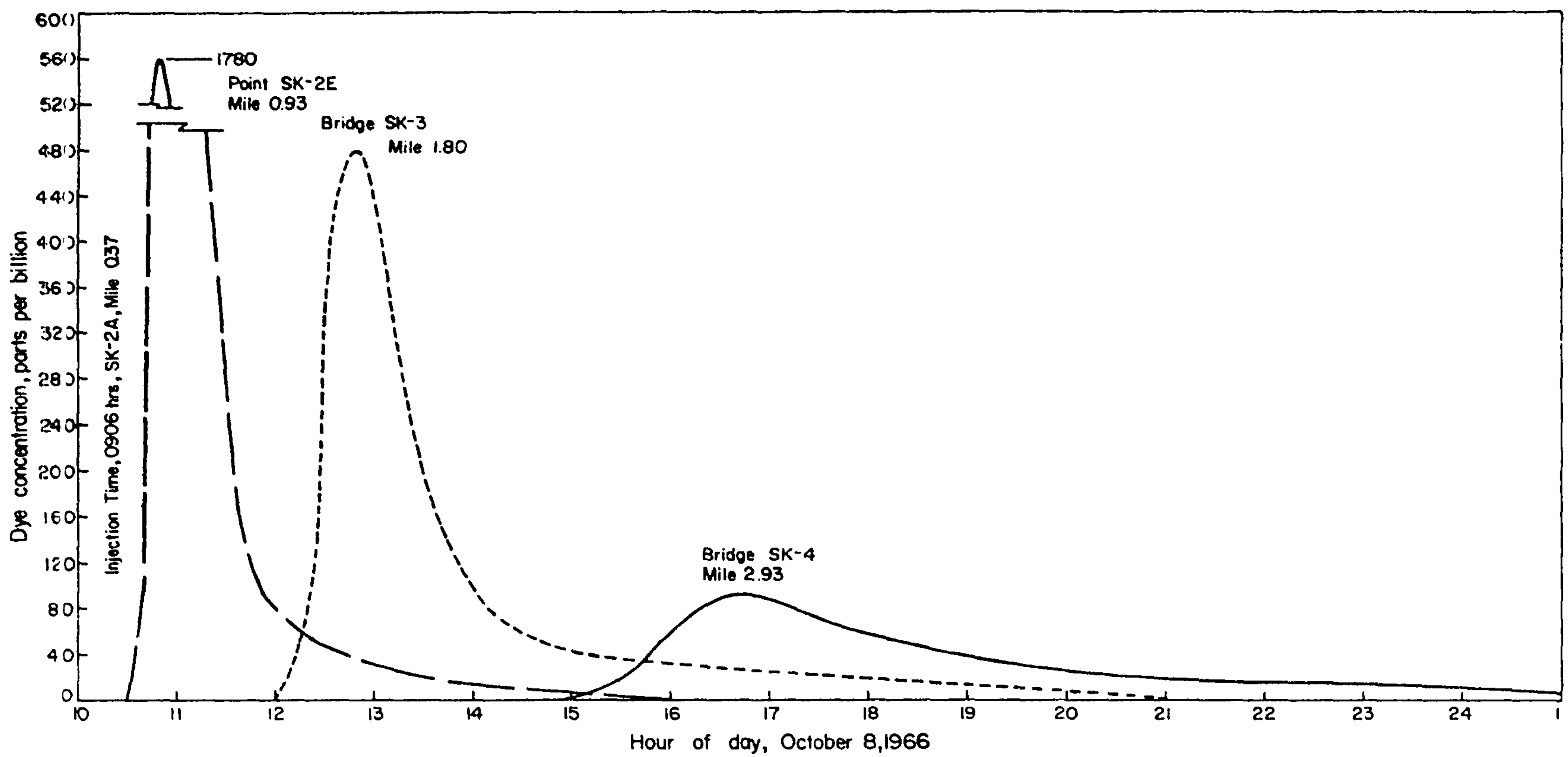
B. Concentration Hydrographs for Dye Tracer Study of August 16, 1966



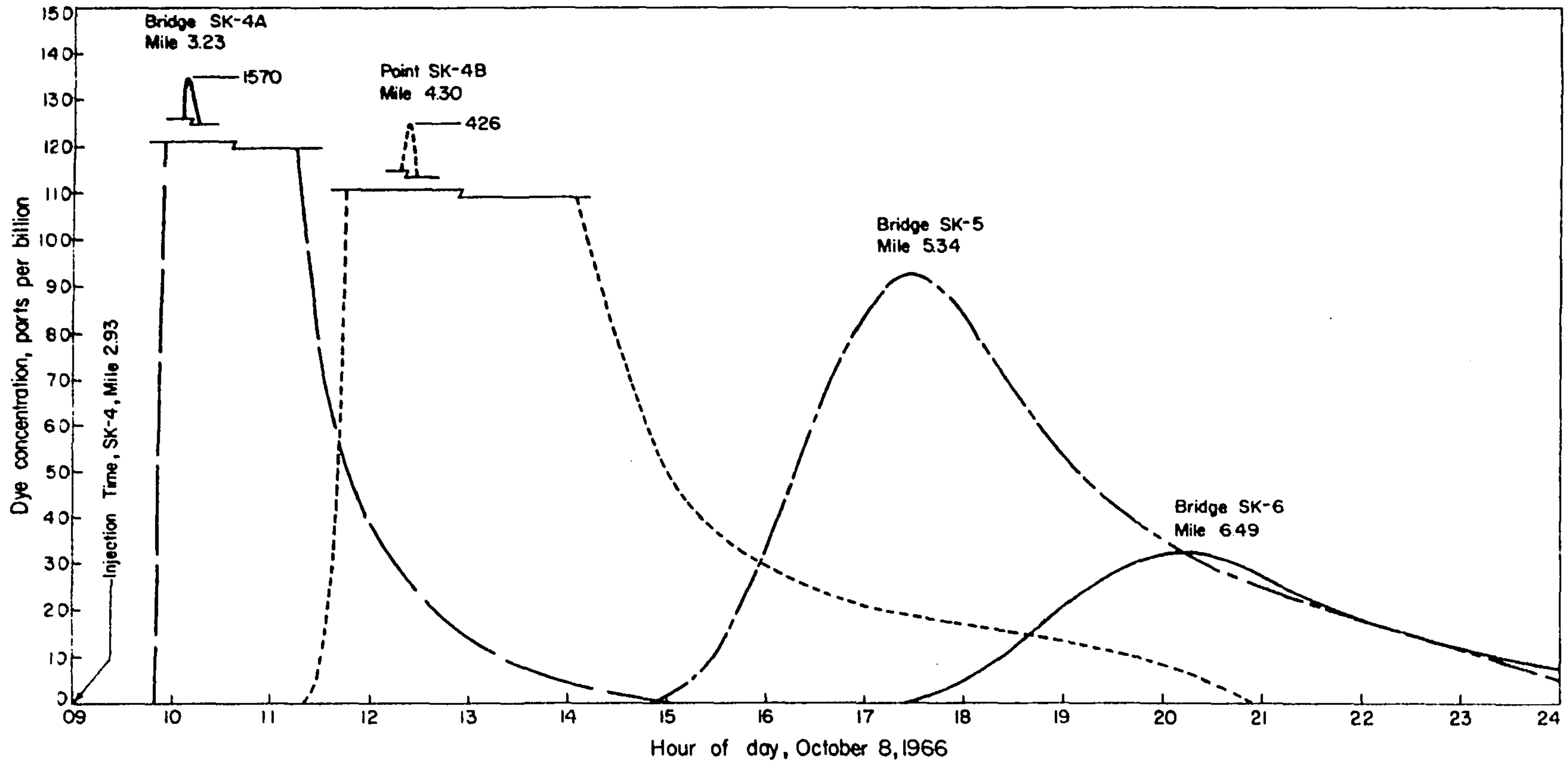
Dye concentration, parts per billion
0
20
40
60
80
100
120
140
160
180
200
220
240
Injection Time, SK-1, Mile 0.0
3040
Outfall
SK-2A
Mile 0.37
Bridge SK-3
Mile 1.80
Bridge SK-4
Mile 2.93
Bridge SK-5
Mile 5.34
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Hour of day, August 16, 1966

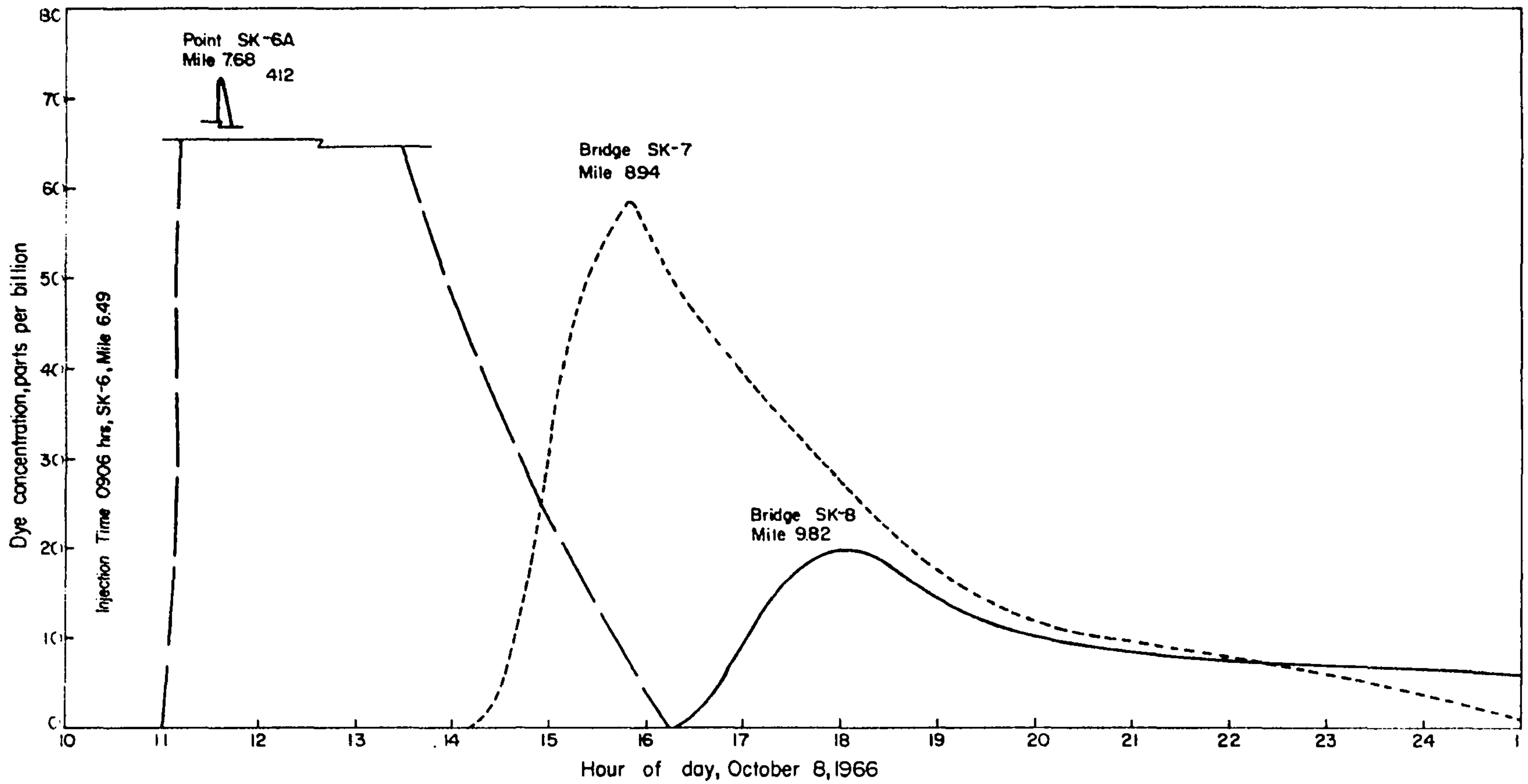

341
Bridge SK-6
Mile 6.49
Road SK-6A
Mile 7.68
Bridge SK-7
Mile 8.94
Bridge SK-8
Mile 9.82
Bridge SK-9
Mile 10.97
Injection Time, SK-5, Mile 5.34
Dye concentration, parts per billion
Hour of day, August 16, 1966

C. Concentration Hydrographs for Dye Tracer Study of October 8, 1966



Dye concentration, parts per billion
600
560
520
480
440
400
360
320
280
240
200
160
120
80
40
0
1780
Point SK-2E
Mile 0.93
Bridge SK-3
Mile 1.80
Injection Time, 0906 hrs, SK-2A, Mile 0.37
Bridge SK-4
Mile 2.93
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
1
Hour of day, October 8, 1966


Dye concentration, parts per billion
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Injection Time, SK-4, Mile 2.93
Bridge SK-4A
Mile 3.23
1570
Point SK-4B
Mile 4.30
426
Bridge SK-5
Mile 5.34
Bridge SK-6
Mile 6.49
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Hour of day, October 8, 1966


Point SK-6A
Mile 7.68
412
Bridge SK-7
Mile 8.94
Bridge SK-8
Mile 9.82
Injection Time 0906 hrs, SK-6, Mile 6.49
Dye concentration, parts per billion
Hour of day, October 8, 1966

XX. APPENDIX C

A. Water and Air Temperature Data for 1966

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
1 1 66	41.00	23.00	36.00	32.00	310.00
1 2 66	40.00	32.00	36.00	33.00	688.00
1 3 66	34.00	15.00	35.00	32.00	875.00
1 4 66	43.00	28.00	37.00	33.00	707.00
1 5 66	46.00	24.00	37.00	33.00	603.00
1 6 66	44.00	6.00	34.00	32.00	470.00
1 7 66	24.00	0.0	32.00	32.00	280.00
1 8 66	2.00	-10.00	32.00	32.00	150.00
1 9 66	39.00	21.00	33.00	32.00	190.00
1 10 66	45.00	11.00	32.00	32.00	206.00
1 11 66	22.00	6.00	32.00	32.00	208.00
1 12 66	27.00	21.00	32.00	32.00	206.00
1 13 66	29.00	13.00	32.00	32.00	200.00
1 14 66	25.00	15.00	33.00	32.00	190.00
1 15 66	26.00	14.00	32.00	32.00	180.00
1 16 66	24.00	11.00	34.00	32.00	170.00
1 17 66	20.00	-6.00	33.00	32.00	158.00
1 18 66	11.00	5.00	33.00	32.00	144.00
1 19 66	18.00	-8.00	33.00	32.00	132.00
1 20 66	19.00	-5.00	33.00	32.00	118.00
1 21 66	23.00	8.00	33.00	32.00	106.00
1 22 66	23.00	-6.00	33.00	32.00	96.00
1 23 66	8.00	-9.00	32.00	32.00	88.00
1 24 66	4.00	-5.00	32.00	32.00	80.00
1 25 66	5.00	2.00	32.00	32.00	73.00
1 26 66	14.00	-1.00	32.00	32.00	67.00
1 27 66	25.00	-4.00	33.00	32.00	62.00
1 28 66	3.00	-11.00	34.00	33.00	56.00
1 29 66	-4.00	-22.00	34.00	33.00	53.00
1 30 66	-1.00	-13.00	34.00	33.00	49.00
1 31 66	12.00	-6.00	34.00	33.00	46.00
2 1 66	22.00	1.00	35.00	33.00	44.00
2 2 66	23.00	-1.00	34.00	33.00	42.00
2 3 66	23.00	7.00	34.00	33.00	41.00
2 4 66	23.00	-2.00	34.00	33.00	40.00
2 5 66	20.00	7.00	34.00	33.00	40.00
2 6 66	35.00	15.00	35.00	33.00	40.00
2 7 66	44.00	24.00	35.00	34.00	41.00
2 8 66	45.00	38.00	33.00	32.00	580.00
2 9 66	56.00	50.00	33.00	32.00	1290.00
2 10 66	56.00	30.00	33.00	32.00	647.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
2 11 66	38.00	30.00	34.00	33.00	400.00
2 12 66	39.00	29.00	36.00	32.00	329.00
2 13 66	50.00	22.00	34.00	32.00	260.00
2 14 66	24.00	12.00	33.00	32.00	180.00
2 15 66	32.00	18.00	34.00	32.00	130.00
2 16 66	41.00	5.00	32.00	32.00	100.00
2 17 66	20.00	5.00	32.00	32.00	78.00
2 18 66	30.00	14.00	32.00	32.00	92.00
2 19 66	18.00	0.0	32.00	32.00	99.00
2 20 66	18.00	-3.00	32.00	32.00	102.00
2 21 66	20.00	2.00	33.00	32.00	104.00
2 22 66	25.00	0.0	33.00	32.00	97.00
2 23 66	30.00	5.00	33.00	32.00	90.00
2 24 66	37.00	9.00	34.00	32.00	85.00
2 25 66	46.00	21.00	35.00	32.00	92.00
2 26 66	41.00	14.00	35.00	32.00	98.00
2 27 66	43.00	27.00	36.00	32.00	102.00
2 28 66	44.00	32.00	39.00	33.00	104.00
3 1 66	51.00	27.00	39.00	32.00	96.00
3 2 66	52.00	35.00	37.00	33.00	106.00
3 3 66	55.00	42.00	43.00	36.00	118.00
3 4 66	60.00	20.00	37.00	32.00	110.00
3 5 66	27.00	19.00	35.00	32.00	80.00
3 6 66	28.00	8.00	35.00	32.00	79.00
3 7 66	27.00	8.00	36.00	33.00	96.00
3 8 66	34.00	26.00	39.00	32.00	112.00
3 9 66	54.00	28.00	45.00	33.00	128.00
3 10 66	57.00	42.00	47.00	40.00	142.00
3 11 66	64.00	46.00	52.00	43.00	148.00
3 12 66	65.00	35.00	54.00	43.00	137.00
3 13 66	59.00	31.00	48.00	43.00	124.00
3 14 66	50.00	27.00	52.00	41.00	114.00
3 15 66	60.00	37.00	52.00	43.00	110.00
3 16 66	69.00	40.00	61.00	47.00	110.00
3 17 66	76.00	50.00	58.00	51.00	119.00
3 18 66	72.00	39.00	52.00	46.00	128.00
3 19 66	55.00	34.00	50.00	42.00	128.00
3 20 66	55.00	28.00	47.00	41.00	149.00
3 21 66	58.00	34.00	45.00	42.00	201.00
3 22 66	59.00	42.00	44.00	41.00	309.00
3 23 66	45.00	22.00	41.00	32.00	926.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
3 24 66	26.00	11.00	34.00	32.00	867.00
3 25 66	25.00	15.00	37.00	32.00	791.00
3 26 66	40.00	22.00	40.00	34.00	735.00
3 27 66	36.00	23.00	39.00	35.00	691.00
3 28 66	38.00	21.00	42.00	37.00	603.00
3 29 66	53.00	38.00	46.00	41.00	615.00
3 30 66	52.00	35.00	50.00	42.00	611.00
3 31 66	64.00	36.00	54.00	45.00	560.00
4 1 66	77.00	41.00	49.00	40.00	497.00
4 2 66	55.00	29.00	45.00	42.00	429.00
4 3 66	54.00	34.00	45.00	42.00	412.00
4 4 66	48.00	31.00	43.00	41.00	429.00
4 5 66	44.00	32.00	41.00	39.00	403.00
4 6 66	40.00	32.00	45.00	36.00	375.00
4 7 66	51.00	31.00	45.00	40.00	346.00
4 8 66	47.00	32.00	47.00	41.00	318.00
4 9 66	49.00	25.00	49.00	38.00	296.00
4 10 66	48.00	24.00	45.00	40.00	290.00
4 11 66	45.00	36.00	42.00	40.00	304.00
4 12 66	48.00	33.00	48.00	39.00	315.00
4 13 66	54.00	33.00	52.00	42.00	298.00
4 14 66	57.00	27.00	54.00	44.00	282.00
4 15 66	61.00	36.00	52.00	47.00	268.00
4 16 66	57.00	35.00	58.00	46.00	260.00
4 17 66	65.00	46.00	56.00	51.00	249.00
4 18 66	66.00	42.00	53.00	49.00	244.00
4 19 66	55.00	45.00	55.00	48.00	239.00
4 20 66	69.00	30.00	49.00	42.00	241.00
4 21 66	41.00	20.00	53.00	39.00	231.00
4 22 66	57.00	30.00	51.00	44.00	218.00
4 23 66	60.00	47.00	52.00	49.00	209.00
4 24 66	59.00	40.00	63.00	47.00	204.00
4 25 66	74.00	41.00	66.00	52.00	192.00
4 26 66	78.00	43.00	69.00	57.00	182.00
4 27 66	78.00	37.00	60.00	49.00	173.00
4 28 66	47.00	32.00	58.00	44.00	163.00
4 29 66	57.00	35.00	53.00	47.00	158.00
4 30 66	55.00	35.00	57.00	45.00	180.00
5 1 66	50.00	30.00	58.00	45.00	173.00
5 2 66	54.00	31.00	64.00	48.00	163.00
5 3 66	70.00	35.00	61.00	50.00	158.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
5 4 66	60.00	41.00	67.00	50.00	146.00
5 5 66	82.00	63.00	72.00	56.00	142.00
5 6 66	89.00	50.00	74.00	60.00	137.00
5 7 66	78.00	51.00	75.00	60.00	133.00
5 8 66	89.00	50.00	67.00	55.00	133.00
5 9 66	54.00	32.00	62.00	48.00	123.00
5 10 66	53.00	30.00	56.00	47.00	116.00
5 11 66	52.00	35.00	48.00	44.00	200.00
5 12 66	44.00	38.00	44.00	43.00	369.00
5 13 66	44.00	40.00	47.00	44.00	422.00
5 14 66	47.00	32.00	56.00	43.00	436.00
5 15 66	65.00	51.00	57.00	52.00	446.00
5 16 66	71.00	39.00	62.00	51.00	436.00
5 17 66	77.00	54.00	61.00	56.00	793.00
5 18 66	72.00	49.00	61.00	53.00	823.00
5 19 66	69.00	45.00	60.00	53.00	631.00
5 20 66	70.00	40.00	59.00	52.00	522.00
5 21 66	60.00	45.00	63.00	54.00	449.00
5 22 66	72.00	53.00	69.00	58.00	393.00
5 23 66	80.00	61.00	68.00	57.00	1640.00
5 24 66	70.00	43.00	59.00	52.00	2510.00
5 25 66	74.00	46.00	63.00	54.00	1440.00
5 26 66	81.00	54.00	66.00	57.00	1050.00
5 27 66	88.00	62.00	67.00	60.00	823.00
5 28 66	85.00	50.00	66.00	59.00	659.00
5 29 66	74.00	46.00	66.00	58.00	553.00
5 30 66	71.00	41.00	66.00	57.00	487.00
5 31 66	72.00	41.00	66.00	57.00	436.00
6 1 66	74.00	42.00	66.00	58.00	403.00
6 2 66	79.00	56.00	64.00	59.00	409.00
6 3 66	69.00	58.00	71.00	60.00	406.00
6 4 66	82.00	62.00	75.00	66.00	387.00
6 5 66	84.00	66.00	73.00	68.00	372.00
6 6 66	76.00	54.00	72.00	64.00	349.00
6 7 66	74.00	51.00	68.00	63.00	321.00
6 8 66	75.00	58.00	66.00	59.00	310.00
6 9 66	65.00	48.00	59.00	54.00	799.00
6 10 66	67.00	43.00	64.00	55.00	955.00
6 11 66	70.00	55.00	68.00	59.00	866.00
6 12 66	82.00	61.00	70.00	63.00	5520.00
6 13 66	79.00	60.00	70.00	62.00	3430.00

ANALYSIS OF AIR AND WATER TEMPERATURES FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
6 14 66	80.00	53.00	72.00	62.00	1850.00
6 15 66	77.00	60.00	69.00	63.00	1280.00
6 16 66	73.00	53.00	65.00	62.00	1060.00
6 17 66	75.00	49.00	64.00	62.00	871.00
6 18 66	75.00	51.00	68.00	58.00	731.00
6 19 66	80.00	58.00	71.00	62.00	600.00
6 20 66	83.00	62.00	72.00	64.00	520.00
6 21 66	88.00	61.00	74.00	66.00	497.00
6 22 66	87.00	63.00	74.00	66.00	425.00
6 23 66	86.00	63.00	75.00	65.00	390.00
6 24 66	87.00	63.00	76.00	67.00	354.00
6 25 66	89.00	69.00	80.00	67.00	318.00
6 26 66	92.00	64.00	79.00	71.00	287.00
6 27 66	82.00	59.00	78.00	69.00	279.00
6 28 66	88.00	64.00	76.00	68.00	580.00
6 29 66	86.00	64.00	79.00	69.00	466.00
6 30 66	88.00	64.00	80.00	70.00	381.00
7 1 66	90.00	66.00	81.00	72.00	321.00
7 2 66	90.00	68.00	82.00	73.00	276.00
7 3 66	92.00	68.00	85.00	73.00	231.00
7 4 66	92.00	67.00	86.00	75.00	204.00
7 5 66	93.00	70.00	83.00	73.00	189.00
7 6 66	91.00	63.00	81.00	69.00	194.00
7 7 66	79.00	59.00	81.00	68.00	153.00
7 8 66	85.00	64.00	78.00	69.00	137.00
7 9 66	87.00	69.00	87.00	72.00	130.00
7 10 66	94.00	73.00	92.00	76.00	114.00
7 11 66	98.00	72.00	91.00	77.00	101.00
7 12 66	97.00	78.00	90.00	77.00	96.00
7 13 66	97.00	75.00	91.00	78.00	86.00
7 14 66	97.00	70.00	84.00	73.00	88.00
7 15 66	83.00	65.00	77.00	70.00	170.00
7 16 66	80.00	58.00	83.00	68.00	115.00
7 17 66	85.00	58.00	85.00	69.00	86.00
7 18 66	90.00	71.00	91.00	74.00	72.00
7 19 66	96.00	65.00	86.00	75.00	62.00
7 20 66	89.00	57.00	81.00	67.00	54.00
7 21 66	78.00	53.00	81.00	65.00	46.00
7 22 66	82.00	50.00	73.00	64.00	39.00
7 23 66	83.00	62.00	80.00	65.00	41.00
7 24 66	81.00	63.00	85.00	69.00	35.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
7 25 66	88.00	65.00	87.00	71.00	31.00
7 26 66	90.00	70.00	80.00	74.00	29.00
7 27 66	85.00	67.00	87.00	71.00	33.00
7 28 66	91.00	68.00	85.00	73.00	40.00
7 29 66	85.00	62.00	79.00	69.00	38.00
7 30 66	78.00	55.00	83.00	65.00	29.00
7 31 66	82.00	56.00	84.00	65.00	24.00
8 1 66	88.00	66.00	79.00	69.00	22.00
8 2 66	88.00	60.00	80.00	64.00	18.00
8 3 66	80.00	50.00	80.00	61.00	15.00
8 4 66	82.00	51.00	79.00	61.00	13.00
8 5 66	83.00	60.00	83.00	64.00	13.00
8 6 66	85.00	59.00	85.00	64.00	12.00
8 7 66	90.00	60.00	84.00	67.00	34.00
8 8 66	87.00	59.00	77.00	65.00	17.00
8 9 66	77.00	51.00	76.00	61.00	13.00
8 10 66	75.00	57.00	78.00	62.00	11.00
8 11 66	77.00	49.00	80.00	59.00	10.00
8 12 66	82.00	54.00	80.00	60.00	9.20
8 13 66	83.00	58.00	69.00	62.00	8.50
8 14 66	76.00	56.00	81.00	60.00	8.50
8 15 66	82.00	63.00	76.00	64.00	9.20
8 16 66	81.00	54.00	84.00	61.00	8.50
8 17 66	88.00	57.00	85.00	65.00	11.00
8 18 66	91.00	62.00	82.00	66.00	11.00
8 19 66	80.00	51.00	81.00	61.00	10.00
8 20 66	83.00	57.00	74.00	63.00	17.00
8 21 66	80.00	67.00	70.00	65.00	55.00
8 22 66	70.00	52.00	67.00	61.00	138.00
8 23 66	67.00	47.00	69.00	57.00	54.00
8 24 66	73.00	44.00	69.00	58.00	35.00
8 25 66	73.00	51.00	76.00	58.00	26.00
8 26 66	80.00	48.00	80.00	59.00	18.00
8 27 66	87.00	53.00	81.00	62.00	15.00
8 28 66	84.00	56.00	81.00	64.00	13.00
8 29 66	86.00	61.00	84.00	66.00	12.00
8 30 66	89.00	62.00	84.00	66.00	10.00
8 31 66	90.00	58.00	82.00	66.00	9.20
9 1 66	88.00	60.00	80.00	67.00	9.20
9 2 66	87.00	65.00	80.00	68.00	8.50
9 3 66	85.00	63.00	76.00	67.00	7.80

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
9 4 66	81.00	61.00	77.00	64.00	7.20
9 5 66	78.00	52.00	74.00	60.00	6.70
9 6 66	77.00	47.00	72.00	55.00	5.70
9 7 66	74.00	41.00	73.00	54.00	5.70
9 8 66	78.00	42.00	74.00	54.00	5.20
9 9 66	80.00	46.00	75.00	55.00	4.30
9 10 66	82.00	47.00	76.00	56.00	4.30
9 11 66	85.00	47.00	76.00	57.00	3.90
9 12 66	83.00	53.00	77.00	59.00	3.90
9 13 66	85.00	53.00	75.00	60.00	3.20
9 14 66	83.00	59.00	67.00	57.00	3.20
9 15 66	67.00	38.00	69.00	49.00	2.80
9 16 66	68.00	33.00	66.00	47.00	2.60
9 17 66	69.00	46.00	71.00	53.00	2.20
9 18 66	73.00	44.00	69.00	52.00	1.80
9 19 66	75.00	50.00	66.00	54.00	1.60
9 20 66	75.00	47.00	72.00	54.00	1.40
9 21 66	78.00	40.00	72.00	50.00	1.30
9 22 66	82.00	48.00	71.00	51.00	1.00
9 23 66	79.00	46.00	70.00	49.00	0.40
9 24 66	74.00	35.00	60.00	47.00	1.00
9 25 66	69.00	50.00	62.00	52.00	1.70
9 26 66	67.00	35.00	54.00	47.00	1.70
9 27 66	57.00	47.00	65.00	50.00	1.40
9 28 66	65.00	44.00	63.00	48.00	1.10
9 29 66	73.00	50.00	60.00	50.00	0.90
9 30 66	61.00	40.00	57.00	46.00	0.70
10 1 66	61.00	33.00	58.00	42.00	0.62
10 2 66	60.00	40.00	62.00	43.00	0.50
10 3 66	75.00	50.00	59.00	48.00	0.40
10 4 66	69.00	40.00	61.00	44.00	0.34
10 5 66	63.00	32.00	63.00	41.00	0.29
10 6 66	64.00	29.00	61.00	40.00	0.26
10 7 66	76.00	45.00	61.00	46.00	0.22
10 8 66	85.00	55.00	68.00	51.00	0.17
10 9 66	82.00	50.00	62.00	51.00	0.10
10 10 66	72.00	38.00	57.00	40.00	0.10
10 11 66	67.00	30.00	62.00	39.00	0.10
10 12 66	74.00	48.00	53.00	46.00	0.11
10 13 66	61.00	53.00	64.00	52.00	0.15
10 14 66	74.00	64.00	69.00	58.00	0.20

ANALYSIS OF AIR AND WATER TEMPERATURES FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
10 15 66	85.00	36.00	58.00	43.00	0.49
10 16 66	44.00	37.00	57.00	41.00	0.47
10 17 66	53.00	25.00	57.00	37.00	0.46
10 18 66	64.00	41.00	47.00	44.00	0.57
10 19 66	52.00	33.00	59.00	38.00	0.63
10 20 66	58.00	30.00	55.00	36.00	0.62
10 21 66	69.00	46.00	54.00	42.00	0.60
10 22 66	69.00	42.00	54.00	40.00	0.76
10 23 66	58.00	29.00	55.00	38.00	0.78
10 24 66	64.00	24.00	55.00	37.00	0.82
10 25 66	60.00	23.00	53.00	38.00	0.86
10 26 66	67.00	31.00	58.00	42.00	0.82
10 27 66	77.00	40.00	60.00	45.00	0.80
10 28 66	82.00	39.00	60.00	43.00	0.78
10 29 66	71.00	28.00	47.00	39.00	0.76
10 30 66	46.00	22.00	49.00	35.00	0.74
10 31 66	62.00	43.00	48.00	41.00	0.71
11 1 66	53.00	28.00	40.00	34.00	0.69
11 2 66	35.00	10.00	42.00	33.00	0.67
11 3 66	32.00	11.00	40.00	32.00	0.64
11 4 66	38.00	28.00	43.00	33.00	0.66
11 5 66	48.00	25.00	47.00	35.00	0.70
11 6 66	50.00	31.00	44.00	37.00	0.62
11 7 66	48.00	32.00	57.00	44.00	0.56
11 8 66	73.00	25.00	48.00	36.00	0.54
11 9 66	37.00	30.00	37.00	32.00	1.80
11 10 66	35.00	16.00	40.00	32.00	1.60
11 11 66	40.00	29.00	38.00	32.00	1.70
11 12 66	41.00	7.00	35.00	32.00	1.40
11 13 66	38.00	28.00	40.00	32.00	1.50
11 14 66	58.00	22.00	42.00	32.00	1.10
11 15 66	50.00	36.00	50.00	35.00	1.50
11 16 66	66.00	35.00	51.00	36.00	1.70
11 17 66	67.00	42.00	49.00	39.00	1.40
11 18 66	55.00	26.00	39.00	32.00	0.82
11 19 66	33.00	13.00	35.00	32.00	0.76
11 20 66	43.00	22.00	39.00	32.00	0.74
11 21 66	53.00	30.00	44.00	32.00	1.10
11 22 66	55.00	47.00	53.00	41.00	1.70
11 23 66	68.00	39.00	48.00	43.00	1.20
11 24 66	56.00	44.00	47.00	42.00	1.10

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 66

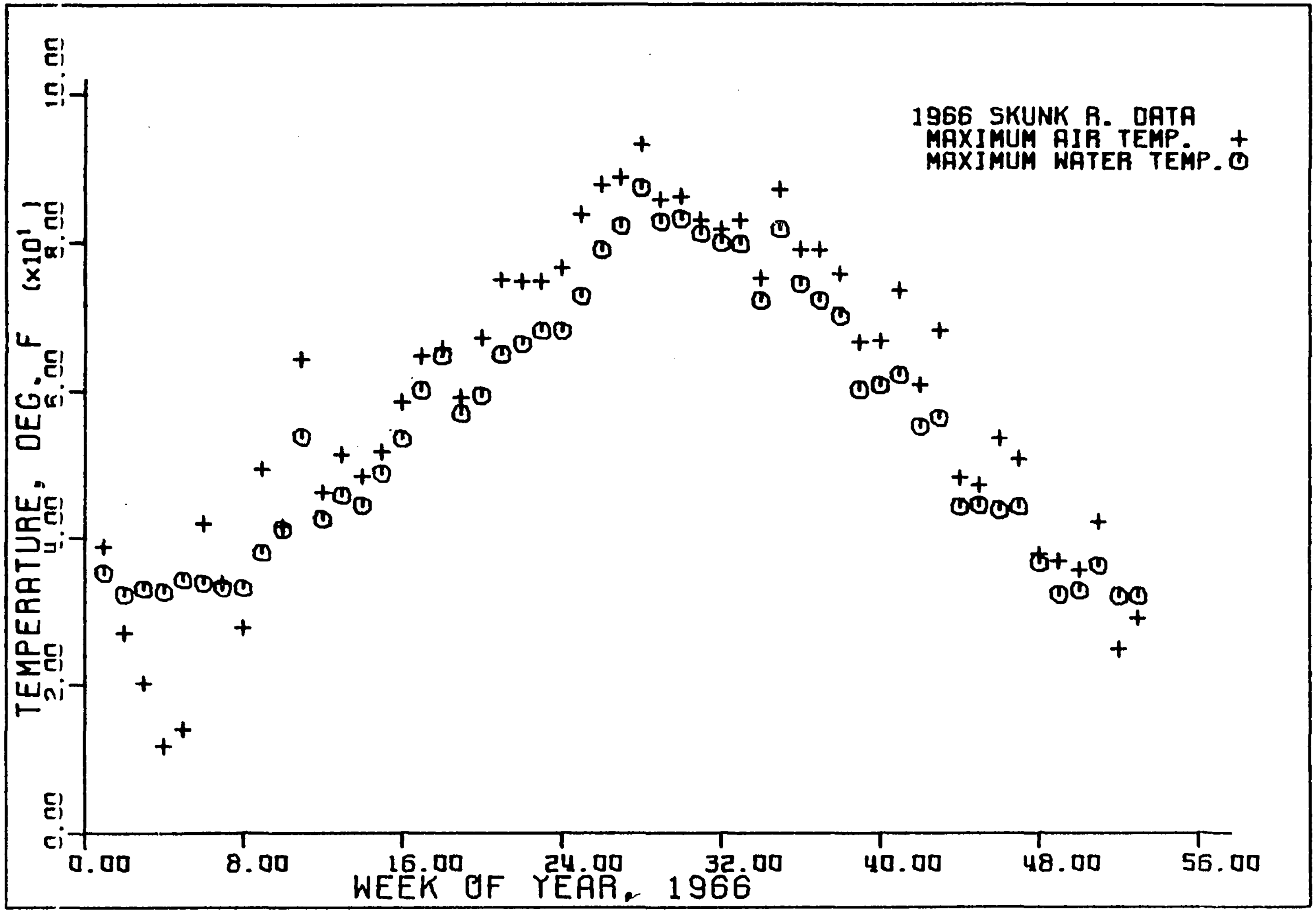
DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
11 25 66	48.00	29.00	43.00	38.00	1.80
11 26 66	49.00	27.00	44.00	35.00	1.30
11 27 66	52.00	31.00	42.00	33.00	0.84
11 28 66	40.00	21.00	39.00	32.00	0.72
11 29 66	40.00	15.00	33.00	32.00	0.64
11 30 66	42.00	17.00	34.00	32.00	0.58
12 1 66	26.00	9.00	32.00	32.00	0.52
12 2 66	16.00	2.00	32.00	32.00	0.48
12 3 66	20.00	2.00	32.00	32.00	0.46
12 4 66	24.00	18.00	32.00	32.00	0.45
12 5 66	33.00	29.00	32.00	32.00	0.56
12 6 66	53.00	35.00	33.00	32.00	0.70
12 7 66	53.00	24.00	33.00	32.00	0.86
12 8 66	37.00	32.00	32.00	32.00	0.93
12 9 66	37.00	26.00	32.00	32.00	0.80
12 10 66	30.00	8.00	32.00	32.00	0.72
12 11 66	20.00	-1.00	32.00	32.00	0.64
12 12 66	27.00	5.00	32.00	32.00	0.56
12 13 66	38.00	13.00	32.00	32.00	0.54
12 14 66	40.00	15.00	32.00	32.00	0.54
12 15 66	49.00	19.00	32.00	32.00	0.54
12 16 66	45.00	20.00	37.00	32.00	0.62
12 17 66	51.00	37.00	48.00	32.00	0.66
12 18 66	52.00	26.00	40.00	32.00	0.68
12 19 66	44.00	27.00	37.00	32.00	0.76
12 20 66	53.00	28.00	33.00	32.00	1.00
12 21 66	39.00	20.00	32.00	32.00	0.90
12 22 66	34.00	12.00	32.00	32.00	0.70
12 23 66	23.00	3.00	32.00	32.00	0.40
12 24 66	28.00	2.00	32.00	32.00	0.10
12 25 66	30.00	5.00	32.00	32.00	0.01
12 26 66	24.00	0.0	32.00	32.00	0.0
12 27 66	23.00	9.00	32.00	32.00	0.0
12 28 66	22.00	18.00	32.00	32.00	0.0
12 29 66	25.00	2.00	32.00	32.00	0.0
12 30 66	22.00	-2.00	32.00	32.00	0.0
12 31 66	29.00	5.00	32.00	32.00	0.0

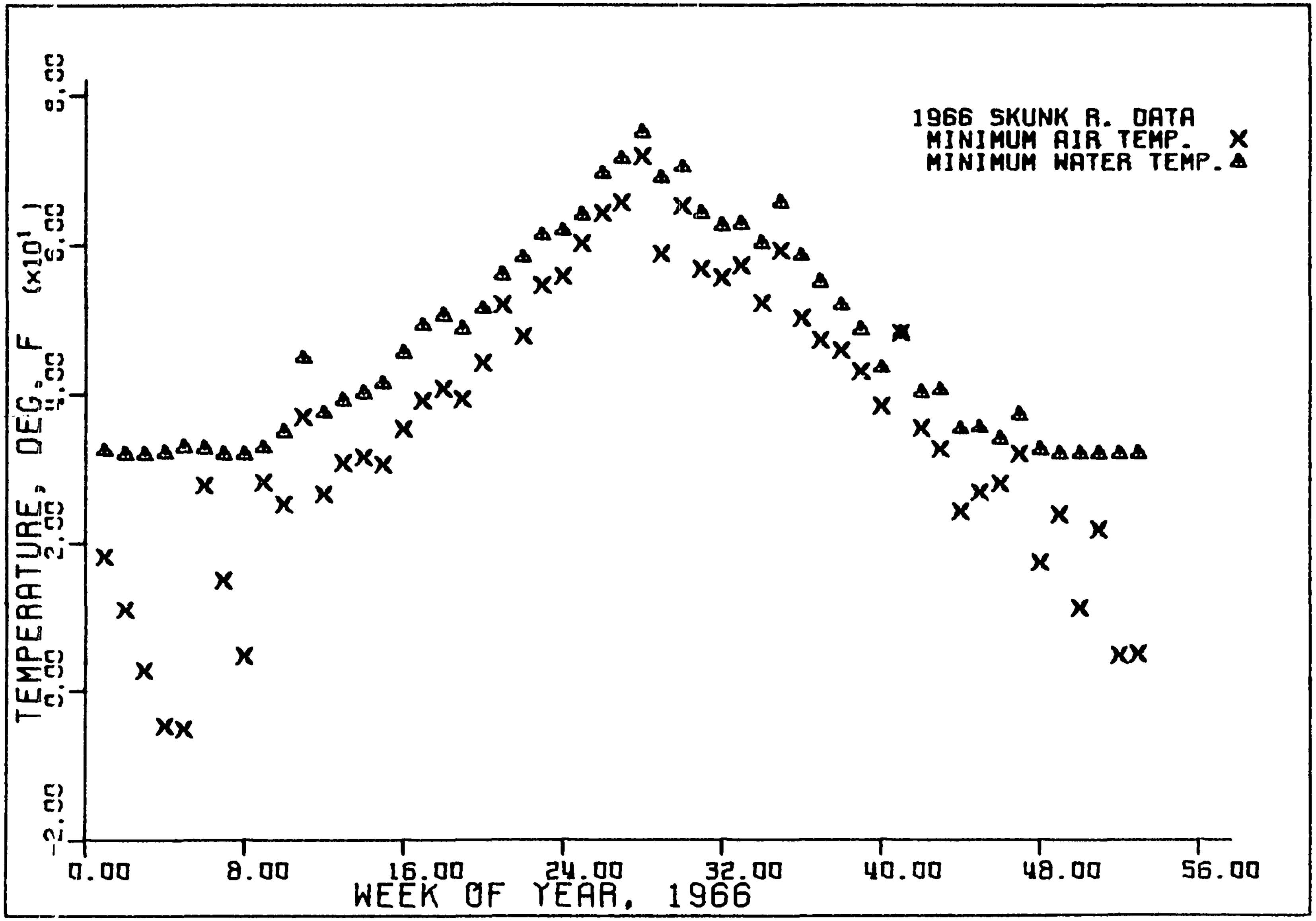
RESULTS OF WEEKLY ANALYSIS OF
AIR AND WATER TEMPERATURES AND RIVER DISCHARGES
FOR THE SKUNK RIVER AT AMES, IOWA

WEEK	BEGINNING DATE	AVERAGE HIGH AIR TEMP. DEG F	AVERAGE LOW AIR TEMP. DEG F	AVERAGE HIGH WATER TEMP. DEG F	AVERAGE LOW WATER TEMP. DEG F	AVERAGE WEEKLY Q CFS	DIFFERENCE MAXIMUM AIR-WTR DEG F	DIFFERENCE MINIMUM AIR-WTR DEG F
1	1 1 66	38.86	18.29	35.29	32.43	561.86	3.57	-14.14
2	1 8 66	27.00	11.00	32.29	32.00	192.86	-5.29	-21.00
3	1 15 66	20.14	2.71	33.00	32.00	144.29	-12.86	-29.29
4	1 22 66	11.71	-4.86	32.57	32.14	74.57	-20.86	-37.00
5	1 29 66	14.00	-5.14	34.14	33.00	45.00	-20.14	-38.14
6	2 5 66	42.00	27.71	33.86	32.71	434.00	8.14	-5.00
7	2 12 66	33.71	15.00	33.29	32.00	167.00	0.43	-17.00
8	2 19 66	27.71	4.86	33.14	32.00	95.57	-5.43	-27.14
9	2 26 66	49.43	28.14	38.00	32.86	104.86	11.43	-4.71
10	3 5 66	41.57	25.29	41.29	35.00	112.14	0.29	-9.71
11	3 12 66	64.43	37.00	53.86	44.86	120.29	10.57	-7.86
12	3 19 66	46.14	26.57	42.57	37.43	481.57	3.57	-10.86
13	3 26 66	51.43	30.86	45.71	39.14	616.00	5.71	-8.29
14	4 2 66	48.43	31.57	44.43	40.14	387.43	4.00	-8.57
15	4 9 66	51.71	30.57	48.86	41.43	293.29	2.86	-10.86
16	4 16 66	58.57	35.43	53.57	45.57	240.29	5.00	-10.14
17	4 23 66	64.71	39.29	60.14	49.29	183.00	4.57	-10.00
18	4 30 66	65.71	40.71	64.71	50.57	157.00	1.00	-9.86
19	5 7 66	59.14	39.43	57.00	48.71	213.71	2.14	-9.29
20	5 14 66	67.29	44.29	59.43	51.43	583.86	7.86	-7.14
21	5 21 66	75.00	52.00	65.00	56.00	1186.43	10.00	-4.00
22	5 28 66	74.86	47.71	66.43	58.29	479.00	8.43	-10.57
23	6 4 66	74.71	54.57	68.14	61.29	499.00	6.57	-6.71
24	6 11 66	76.57	55.86	68.29	61.86	2125.29	8.29	-6.00
25	6 18 66	83.71	60.14	72.86	64.00	502.43	10.86	-3.86
26	6 25 66	87.86	64.29	79.00	69.43	376.00	8.86	-5.14
27	7 2 66	88.86	65.57	82.29	71.43	197.71	6.57	-5.86

RESULTS OF WEEKLY ANALYSIS OF
AIR AND WATER TEMPERATURES AND RIVER DISCHARGES
FOR THE SKUNK RIVER AT AMES, IOWA

WEEK	BEGINNING DATE	AVERAGE HIGH AIR TEMP. DEG F	AVERAGE LOW AIR TEMP. DEG F	AVERAGE HIGH WATER TEMP. DEG F	AVERAGE LOW WATER TEMP. DEG F	AVERAGE WEEKLY Q CFS	DIFFERENCE MAXIMUM AIR-WTR DEG F	DIFFERENCE MINIMUM AIR-WTR DEG F
28	7 9 66	93.29	71.71	87.43	75.00	112.43	5.86	-3.29
29	7 16 66	85.71	58.86	82.86	68.86	67.71	2.86	-10.00
30	7 23 66	86.14	65.29	83.29	70.29	35.29	2.86	-5.00
31	7 30 66	83.00	56.86	81.14	64.14	19.14	1.86	-7.29
32	8 6 66	81.86	55.57	80.00	62.57	15.17	1.86	-7.00
33	8 13 66	83.00	57.29	79.71	62.71	9.53	3.29	-5.43
34	8 20 66	75.14	52.29	72.14	60.14	49.00	3.00	-7.86
35	8 27 66	87.29	59.29	81.71	65.57	10.99	5.57	-6.29
36	9 3 66	79.00	50.29	74.43	58.43	6.09	4.57	-8.14
37	9 10 66	79.00	47.14	72.29	55.00	3.41	6.71	-7.86
38	9 17 66	75.86	45.86	70.14	51.86	1.39	5.71	-6.00
39	9 24 66	66.57	43.00	60.14	48.57	1.21	6.43	-5.57
40	10 1 66	66.86	38.43	60.71	43.43	0.38	6.14	-5.00
41	10 8 66	73.57	48.29	62.14	48.14	0.13	11.43	0.14
42	10 15 66	60.71	35.43	55.29	40.14	0.55	5.43	-4.71
43	10 22 66	68.14	32.57	56.43	40.43	0.80	11.71	-7.86
44	10 29 66	48.14	24.29	44.14	35.29	0.70	4.00	-11.00
45	11 5 66	47.29	26.86	44.43	35.43	1.07	2.86	-8.57
46	11 12 66	53.57	28.00	43.71	34.00	1.35	9.86	-6.00
47	11 19 66	50.86	32.00	44.14	37.14	1.20	6.71	-5.14
48	11 26 66	37.86	17.43	36.57	32.57	0.73	1.29	-15.14
49	12 3 66	36.71	23.71	32.29	32.00	0.68	4.43	-8.29
50	12 10 66	35.57	11.29	32.71	32.00	0.59	2.86	-20.71
51	12 17 66	42.29	21.86	36.29	32.00	0.73	6.00	-10.14
52	12 24 66	24.86	4.86	32.00	32.00	0.02	-7.14	-27.14
53	12 31 66	29.00	5.00	32.00	32.00	0.0	-3.00	-27.00


1966 SKUNK R. DATA
MAXIMUM AIR TEMP. +
MAXIMUM WATER TEMP. ⊙
TEMPERATURE, DEG. F (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
WEEK OF YEAR, 1966


1966 SKUNK R. DATA
MINIMUM AIR TEMP. X
MINIMUM WATER TEMP. Δ
TEMPERATURE, DEG. F (x10¹)
8.00
6.00
4.00
2.00
0.00
-2.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
WEEK OF YEAR, 1966

B. Water and Air Temperature Data for 1967

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
1 1 67	33.00	12.00	32.00	32.00	0.0
1 2 67	37.00	19.00	32.00	32.00	0.0
1 3 67	34.00	5.00	32.00	32.00	0.0
1 4 67	26.00	19.00	32.00	32.00	0.0
1 5 67	22.00	9.00	32.00	32.00	0.0
1 6 67	34.00	22.00	32.00	32.00	0.0
1 7 67	41.00	20.00	32.00	32.00	0.0
1 8 67	26.00	-6.00	32.00	32.00	0.0
1 9 67	21.00	10.00	32.00	32.00	0.0
1 10 67	35.00	16.00	32.00	32.00	0.0
1 11 67	22.00	-1.00	32.00	32.00	0.0
1 12 67	36.00	21.00	32.00	32.00	0.0
1 13 67	37.00	20.00	32.00	32.00	0.0
1 14 67	42.00	25.00	32.00	32.00	0.0
1 15 67	30.00	0.0	32.00	32.00	0.0
1 16 67	33.00	15.00	32.00	32.00	0.0
1 17 67	40.00	-9.00	32.00	32.00	0.0
1 18 67	2.00	-22.00	32.00	32.00	0.0
1 19 67	9.00	-6.00	32.00	32.00	0.02
1 20 67	32.00	11.00	36.00	32.00	0.04
1 21 67	46.00	26.00	39.00	32.00	0.11
1 22 67	50.00	31.00	36.00	32.00	0.37
1 23 67	49.00	30.00	38.00	32.00	1.10
1 24 67	43.00	33.00	34.00	32.00	3.20
1 25 67	56.00	15.00	32.00	32.00	7.60
1 26 67	27.00	16.00	32.00	32.00	4.50
1 27 67	25.00	8.00	32.00	32.00	5.00
1 28 67	31.00	5.00	32.00	32.00	5.20
1 29 67	38.00	25.00	32.00	32.00	12.00
1 30 67	39.00	24.00	32.00	32.00	11.00
1 31 67	33.00	25.00	32.00	32.00	5.20
2 1 67	40.00	23.00	32.00	32.00	1.90
2 2 67	26.00	3.00	32.00	32.00	0.60
2 3 67	27.00	10.00	32.00	32.00	0.21
2 4 67	39.00	33.00	32.00	32.00	0.07
2 5 67	40.00	26.00	32.00	32.00	0.02
2 6 67	28.00	-2.00	32.00	32.00	0.0
2 7 67	18.00	0.0	32.00	32.00	0.0
2 8 67	28.00	15.00	32.00	32.00	0.0
2 9 67	38.00	18.00	32.00	32.00	0.0
2 10 67	45.00	33.00	32.00	32.00	0.0

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
2 11 67	39.00	7.00	32.00	32.00	0.0
2 12 67	13.00	0.0	32.00	32.00	0.0
2 13 67	37.00	19.00	32.00	32.00	0.0
2 14 67	58.00	32.00	32.00	32.00	0.0
2 15 67	64.00	29.00	32.00	32.00	0.0
2 16 67	33.00	-7.00	32.00	32.00	0.0
2 17 67	15.00	7.00	32.00	32.00	0.0
2 18 67	23.00	14.00	32.00	32.00	0.0
2 19 67	30.00	24.00	32.00	32.00	0.0
2 20 67	29.00	0.0	32.00	32.00	0.0
2 21 67	18.00	-1.00	32.00	32.00	0.0
2 22 67	42.00	8.00	32.00	32.00	0.0
2 23 67	23.00	7.00	32.00	32.00	0.0
2 24 67	15.00	-3.00	32.00	32.00	0.0
2 25 67	11.00	-10.00	32.00	32.00	0.0
2 26 67	25.00	11.00	32.00	32.00	0.0
2 27 67	48.00	30.00	32.00	32.00	0.0
2 28 67	38.00	21.00	32.00	32.00	0.0
3 1 67	40.00	20.00	32.00	32.00	0.0
3 2 67	54.00	28.00	44.00	32.00	0.0
3 3 67	53.00	29.00	42.00	32.00	0.0
3 4 67	40.00	23.00	32.00	32.00	0.0
3 5 67	37.00	20.00	32.00	32.00	0.0
3 6 67	37.00	12.00	33.00	32.00	0.0
3 7 67	43.00	-1.00	32.00	32.00	0.0
3 8 67	15.00	-4.00	32.00	32.00	0.0
3 9 67	34.00	21.00	32.00	32.00	1.40
3 10 67	62.00	29.00	32.00	32.00	2.60
3 11 67	70.00	28.00	32.00	32.00	7.00
3 12 67	55.00	30.00	32.00	32.00	17.00
3 13 67	39.00	30.00	32.00	32.00	15.00
3 14 67	41.00	28.00	32.00	32.00	14.00
3 15 67	35.00	24.00	32.00	32.00	14.00
3 16 67	40.00	14.00	34.00	32.00	13.00
3 17 67	52.00	9.00	32.00	32.00	14.00
3 18 67	30.00	5.00	32.00	32.00	14.00
3 19 67	36.00	23.00	32.00	32.00	14.00
3 20 67	36.00	30.00	32.00	32.00	16.00
3 21 67	39.00	31.00	41.00	32.00	13.00
3 22 67	52.00	26.00	44.00	32.00	10.00
3 23 67	68.00	25.00	46.00	32.00	13.00

ANALYSIS OF AIR AND WATER TEMPERATURES FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
3 24 67	62.00	41.00	60.00	37.00	15.00
3 25 67	82.00	45.00	52.00	46.00	22.00
3 26 67	53.00	38.00	46.00	41.00	57.00
3 27 67	44.00	36.00	54.00	41.00	38.00
3 28 67	60.00	36.00	62.00	44.00	31.00
3 29 67	65.00	40.00	62.00	46.00	21.00
3 30 67	72.00	64.00	66.00	55.00	18.00
3 31 67	81.00	44.00	61.00	51.00	14.00
4 1 67	66.00	41.00	58.00	48.00	12.00
4 2 67	67.00	55.00	60.00	48.00	12.00
4 3 67	66.00	29.00	64.00	43.00	9.80
4 4 67	67.00	36.00	60.00	44.00	9.20
4 5 67	67.00	41.00	62.00	49.00	9.20
4 6 67	76.00	44.00	57.00	44.00	7.80
4 7 67	65.00	32.00	64.00	41.00	6.70
4 8 67	61.00	43.00	50.00	46.00	6.70
4 9 67	55.00	47.00	60.00	44.00	7.20
4 10 67	65.00	29.00	63.00	40.00	6.20
4 11 67	55.00	27.00	58.00	41.00	5.20
4 12 67	55.00	39.00	46.00	44.00	6.70
4 13 67	50.00	43.00	55.00	44.00	26.00
4 14 67	65.00	50.00	60.00	50.00	23.00
4 15 67	65.00	39.00	70.00	48.00	23.00
4 16 67	80.00	59.00	78.00	57.00	19.00
4 17 67	87.00	40.00	53.00	43.00	14.00
4 18 67	55.00	32.00	65.00	44.00	9.80
4 19 67	60.00	34.00	67.00	44.00	7.20
4 20 67	65.00	45.00	59.00	49.00	40.00
4 21 67	62.00	42.00	58.00	47.00	26.00
4 22 67	59.00	30.00	55.00	40.00	17.00
4 23 67	49.00	27.00	46.00	39.00	15.00
4 24 67	41.00	23.00	61.00	35.00	13.00
4 25 67	53.00	35.00	48.00	42.00	10.00
4 26 67	49.00	34.00	54.00	41.00	14.00
4 27 67	54.00	35.00	64.00	42.00	10.00
4 28 67	62.00	39.00	68.00	46.00	9.80
4 29 67	70.00	57.00	59.00	55.00	8.50
4 30 67	64.00	57.00	76.00	54.00	7.80
5 1 67	85.00	40.00	62.00	45.00	6.70
5 2 67	54.00	30.00	64.00	39.00	5.70
5 3 67	54.00	31.00	54.00	42.00	3.90

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
5 4 67	46.00	34.00	67.00	42.00	3.20
5 5 67	55.00	42.00	53.00	46.00	3.20
5 6 67	50.00	32.00	57.00	41.00	2.90
5 7 67	58.00	31.00	70.00	41.00	2.70
5 8 67	73.00	46.00	70.00	45.00	2.50
5 9 67	67.00	38.00	77.00	44.00	2.30
5 10 67	71.00	50.00	65.00	52.00	5.00
5 11 67	75.00	45.00	57.00	49.00	16.00
5 12 67	50.00	41.00	62.00	47.00	29.00
5 13 67	57.00	39.00	66.00	50.00	26.00
5 14 67	65.00	47.00	63.00	52.00	16.00
5 15 67	63.00	39.00	69.00	48.00	12.00
5 16 67	65.00	33.00	69.00	48.00	9.20
5 17 67	70.00	44.00	82.00	53.00	6.70
5 18 67	77.00	59.00	84.00	56.00	5.20
5 19 67	92.00	50.00	74.00	52.00	3.20
5 20 67	73.00	38.00	75.00	48.00	2.50
5 21 67	67.00	42.00	79.00	51.00	1.80
5 22 67	75.00	37.00	74.00	49.00	1.70
5 23 67	75.00	59.00	83.00	54.00	1.50
5 24 67	89.00	48.00	82.00	56.00	1.40
5 25 67	93.00	62.00	75.00	60.00	1.30
5 26 67	98.00	67.00	78.00	62.00	1.20
5 27 67	94.00	62.00	71.00	60.00	1.10
5 28 67	81.00	50.00	62.00	50.00	1.40
5 29 67	57.00	48.00	57.00	54.00	1.60
5 30 67	57.00	49.00	53.00	51.00	21.00
5 31 67	52.00	49.00	60.00	49.00	10.00
6 1 67	64.00	49.00	75.00	51.00	6.20
6 2 67	71.00	43.00	80.00	54.00	4.60
6 3 67	78.00	45.00	80.00	56.00	3.30
6 4 67	80.00	54.00	82.00	60.00	2.80
6 5 67	83.00	62.00	70.00	65.00	77.00
6 6 67	65.00	60.00	69.00	63.00	265.00
6 7 67	80.00	65.00	69.00	65.00	400.00
6 8 67	75.00	60.00	69.00	62.00	4070.00
6 9 67	80.00	61.00	68.00	64.00	3420.00
6 10 67	78.00	60.00	67.00	63.00	2620.00
6 11 67	81.00	64.00	72.00	65.00	2190.00
6 12 67	77.00	59.00	66.00	60.00	3420.00
6 13 67	81.00	61.00	68.00	65.00	3010.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
6 14 67	78.00	67.00	72.00	64.00	2720.00
6 15 67	84.00	68.00	80.00	63.00	1500.00
6 16 67	84.00	64.00	68.00	62.00	1870.00
6 17 67	81.00	64.00	67.00	65.00	2400.00
6 18 67	75.00	62.00	66.00	63.00	2300.00
6 19 67	70.00	63.00	80.00	63.00	1340.00
6 20 67	82.00	55.00	71.00	56.00	1040.00
6 21 67	80.00	63.00	71.00	67.00	819.00
6 22 67	77.00	52.00	72.00	64.00	643.00
6 23 67	79.00	63.00	71.00	67.00	518.00
6 24 67	75.00	49.00	68.00	59.00	355.00
6 25 67	65.00	49.00	64.00	57.00	1830.00
6 26 67	76.00	51.00	67.00	61.00	1030.00
6 27 67	78.00	54.00	67.00	63.00	747.00
6 28 67	76.00	52.00	69.00	61.00	811.00
6 29 67	80.00	61.00	73.00	64.00	939.00
6 30 67	83.00	62.00	77.00	67.00	651.00
7 1 67	88.00	65.00	75.00	70.00	483.00
7 2 67	80.00	54.00	71.00	66.00	375.00
7 3 67	72.00	47.00	68.00	61.00	304.00
7 4 67	70.00	46.00	70.00	59.00	257.00
7 5 67	70.00	44.00	71.00	60.00	216.00
7 6 67	75.00	46.00	74.00	61.00	185.00
7 7 67	79.00	49.00	71.00	63.00	163.00
7 8 67	83.00	56.00	69.00	66.00	168.00
7 9 67	79.00	64.00	75.00	66.00	211.00
7 10 67	84.00	65.00	84.00	70.00	192.00
7 11 67	89.00	64.00	85.00	72.00	163.00
7 12 67	87.00	54.00	80.00	69.00	130.00
7 13 67	84.00	51.00	72.00	64.00	101.00
7 14 67	72.00	47.00	76.00	60.00	87.00
7 15 67	80.00	47.00	77.00	63.00	77.00
7 16 67	82.00	51.00	78.00	65.00	70.00
7 17 67	82.00	58.00	80.00	67.00	64.00
7 18 67	84.00	62.00	81.00	69.00	62.00
7 19 67	87.00	62.00	85.00	70.00	56.00
7 20 67	87.00	64.00	83.00	72.00	52.00
7 21 67	87.00	64.00	85.00	71.00	46.00
7 22 67	90.00	67.00	88.00	71.00	42.00
7 23 67	94.00	73.00	89.00	75.00	38.00
7 24 67	95.00	64.00	89.00	72.00	35.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
7 25 67	93.00	56.00	83.00	69.00	31.00
7 26 67	88.00	60.00	88.00	69.00	31.00
7 27 67	93.00	63.00	78.00	69.00	39.00
7 28 67	78.00	56.00	84.00	65.00	37.00
7 29 67	82.00	57.00	87.00	67.00	35.00
7 30 67	90.00	60.00	76.00	68.00	33.00
7 31 67	82.00	62.00	87.00	68.00	31.00
8 1 67	85.00	64.00	76.00	71.00	29.00
8 2 67	81.00	65.00	86.00	69.00	28.00
8 3 67	88.00	59.00	85.00	67.00	31.00
8 4 67	85.00	55.00	82.00	65.00	27.00
8 5 67	80.00	54.00	77.00	65.00	24.00
8 6 67	80.00	64.00	82.00	66.00	22.00
8 7 67	86.00	60.00	83.00	67.00	21.00
8 8 67	82.00	66.00	82.00	69.00	45.00
8 9 67	84.00	59.00	75.00	70.00	243.00
8 10 67	76.00	48.00	74.00	64.00	162.00
8 11 67	73.00	46.00	77.00	62.00	87.00
8 12 67	75.00	45.00	79.00	62.00	60.00
8 13 67	81.00	49.00	79.00	64.00	48.00
8 14 67	83.00	54.00	77.00	65.00	36.00
8 15 67	82.00	57.00	80.00	65.00	28.00
8 16 67	87.00	58.00	82.00	65.00	22.00
8 17 67	89.00	65.00	83.00	68.00	20.00
8 18 67	88.00	63.00	75.00	65.00	18.00
8 19 67	72.00	49.00	76.00	60.00	17.00
8 20 67	72.00	42.00	78.00	58.00	15.00
8 21 67	83.00	53.00	80.00	63.00	14.00
8 22 67	86.00	58.00	71.00	65.00	19.00
8 23 67	74.00	58.00	78.00	63.00	21.00
8 24 67	86.00	62.00	80.00	65.00	16.00
8 25 67	85.00	51.00	78.00	65.00	13.00
8 26 67	85.00	61.00	73.00	64.00	11.00
8 27 67	73.00	45.00	74.00	58.00	10.00
8 28 67	75.00	41.00	76.00	59.00	8.50
8 29 67	85.00	57.00	76.00	63.00	6.90
8 30 67	85.00	51.00	72.00	60.00	6.00
8 31 67	72.00	41.00	71.00	55.00	5.30
9 1 67	70.00	37.00	71.00	53.00	4.70
9 2 67	73.00	41.00	71.00	54.00	4.70
9 3 67	75.00	46.00	69.00	55.00	4.60

ANALYSIS OF AIR AND WATER TEMPERATURES FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
9 4 67	76.00	43.00	70.00	54.00	3.90
9 5 67	78.00	44.00	74.00	53.00	3.50
9 6 67	80.00	46.00	71.00	53.00	3.20
9 7 67	81.00	48.00	76.00	53.00	2.90
9 8 67	83.00	50.00	73.00	56.00	2.60
9 9 67	85.00	45.00	73.00	53.00	2.40
9 10 67	75.00	42.00	70.00	52.00	2.50
9 11 67	72.00	45.00	72.00	51.00	2.30
9 12 67	78.00	55.00	66.00	55.00	2.20
9 13 67	88.00	64.00	63.00	61.00	13.00
9 14 67	67.00	54.00	65.00	59.00	11.00
9 15 67	69.00	55.00	75.00	61.00	8.80
9 16 67	79.00	48.00	75.00	61.00	7.20
9 17 67	82.00	52.00	69.00	54.00	4.90
9 18 67	75.00	55.00	67.00	62.00	4.00
9 19 67	72.00	57.00	70.00	62.00	3.30
9 20 67	74.00	62.00	68.00	62.00	3.60
9 21 67	73.00	53.00	70.00	55.00	3.60
9 22 67	72.00	42.00	69.00	51.00	4.30
9 23 67	71.00	44.00	67.00	54.00	3.60
9 24 67	70.00	36.00	65.00	49.00	3.00
9 25 67	69.00	39.00	70.00	48.00	3.50
9 26 67	85.00	56.00	62.00	48.00	3.30
9 27 67	63.00	35.00	55.00	47.00	3.10
9 28 67	56.00	30.00	58.00	40.00	2.90
9 29 67	58.00	27.00	59.00	38.00	2.50
9 30 67	65.00	35.00	65.00	40.00	2.20
10 1 67	79.00	46.00	77.00	46.00	1.60
10 2 67	84.00	53.00	80.00	53.00	1.70
10 3 67	86.00	52.00	83.00	52.00	1.90
10 4 67	84.00	57.00	81.00	57.00	1.80
10 5 67	82.00	47.00	71.00	48.00	1.70
10 6 67	70.00	48.00	77.00	49.00	1.50
10 7 67	68.00	48.00	56.00	49.00	2.40
10 8 67	60.00	44.00	52.00	46.00	5.40
10 9 67	48.00	38.00	48.00	44.00	5.20
10 10 67	50.00	36.00	47.00	40.00	4.80
10 11 67	47.00	22.00	55.00	38.00	4.30
10 12 67	60.00	34.00	59.00	42.00	4.00
10 13 67	72.00	52.00	64.00	51.00	4.60
10 14 67	68.00	36.00	64.00	48.00	4.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
10 15 67	74.00	48.00	56.00	50.00	3.40
10 16 67	62.00	33.00	61.00	44.00	2.80
10 17 67	65.00	30.00	60.00	42.00	2.40
10 18 67	69.00	37.00	54.00	40.00	2.10
10 19 67	57.00	25.00	55.00	39.00	1.80
10 20 67	60.00	36.00	54.00	40.00	1.60
10 21 67	60.00	24.00	55.00	37.00	2.20
10 22 67	70.00	42.00	61.00	42.00	2.20
10 23 67	79.00	56.00	63.00	50.00	2.20
10 24 67	76.00	49.00	55.00	44.00	5.70
10 25 67	55.00	37.00	49.00	40.00	6.70
10 26 67	47.00	24.00	40.00	37.00	6.70
10 27 67	36.00	24.00	39.00	35.00	6.20
10 28 67	39.00	17.00	42.00	32.00	5.70
10 29 67	46.00	38.00	42.00	37.00	10.00
10 30 67	50.00	34.00	42.00	39.00	12.00
10 31 67	43.00	28.00	45.00	37.00	15.00
11 1 67	48.00	41.00	46.00	41.00	17.00
11 2 67	48.00	35.00	44.00	39.00	12.00
11 3 67	42.00	26.00	43.00	34.00	9.80
11 4 67	40.00	20.00	37.00	32.00	7.20
11 5 67	32.00	21.00	37.00	32.00	6.20
11 6 67	37.00	13.00	40.00	32.00	5.20
11 7 67	42.00	13.00	40.00	32.00	3.60
11 8 67	44.00	23.00	45.00	32.00	3.60
11 9 67	62.00	24.00	47.00	33.00	3.20
11 10 67	62.00	41.00	45.00	33.00	3.60
11 11 67	55.00	38.00	53.00	40.00	3.90
11 12 67	68.00	35.00	48.00	38.00	3.60
11 13 67	48.00	27.00	43.00	38.00	3.60
11 14 67	38.00	30.00	47.00	34.00	3.20
11 15 67	53.00	16.00	42.00	32.00	3.20
11 16 67	43.00	25.00	41.00	32.00	2.80
11 17 67	48.00	33.00	46.00	34.00	2.80
11 18 67	56.00	32.00	43.00	32.00	2.60
11 19 67	48.00	16.00	41.00	32.00	2.80
11 20 67	45.00	24.00	40.00	33.00	2.80
11 21 67	43.00	20.00	40.00	32.00	2.80
11 22 67	45.00	28.00	37.00	32.00	2.60
11 23 67	35.00	12.00	36.00	32.00	2.00
11 24 67	47.00	25.00	41.00	32.00	2.60

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 67

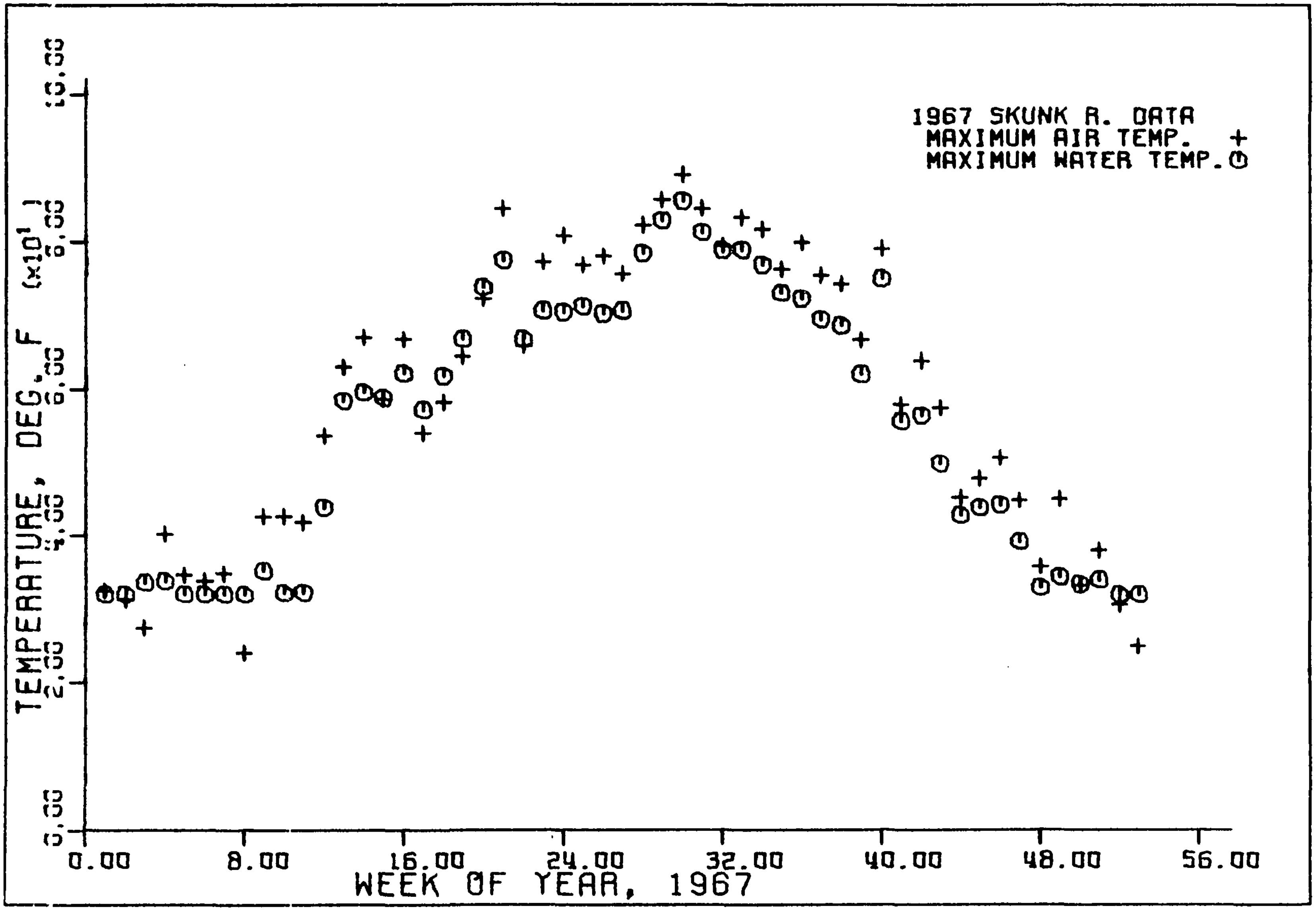
DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
11 25 67	51.00	21.00	39.00	32.00	2.80
11 26 67	43.00	21.00	38.00	32.00	2.60
11 27 67	40.00	15.00	33.00	32.00	2.50
11 28 67	31.00	9.00	32.00	32.00	2.40
11 29 67	31.00	22.00	32.00	32.00	2.30
11 30 67	32.00	26.00	32.00	32.00	2.20
12 1 67	39.00	26.00	32.00	32.00	2.30
12 2 67	35.00	30.00	32.00	32.00	2.50
12 3 67	37.00	12.00	32.00	32.00	2.70
12 4 67	50.00	23.00	32.00	32.00	2.90
12 5 67	45.00	22.00	36.00	32.00	3.10
12 6 67	54.00	25.00	35.00	32.00	3.20
12 7 67	47.00	35.00	36.00	32.00	6.20
12 8 67	42.00	32.00	36.00	33.00	5.70
12 9 67	40.00	36.00	34.00	33.00	6.70
12 10 67	35.00	30.00	36.00	34.00	7.80
12 11 67	35.00	25.00	34.00	33.00	7.20
12 12 67	36.00	28.00	36.00	32.00	7.80
12 13 67	38.00	17.00	32.00	32.00	4.30
12 14 67	32.00	17.00	32.00	32.00	3.60
12 15 67	26.00	9.00	32.00	32.00	3.20
12 16 67	30.00	15.00	32.00	32.00	2.80
12 17 67	35.00	29.00	32.00	32.00	3.60
12 18 67	47.00	25.00	32.00	32.00	3.20
12 19 67	40.00	20.00	33.00	32.00	2.80
12 20 67	45.00	34.00	40.00	32.00	3.60
12 21 67	56.00	18.00	37.00	32.00	2.00
12 22 67	22.00	4.00	32.00	32.00	1.00
12 23 67	21.00	3.00	32.00	32.00	0.54
12 24 67	39.00	14.00	32.00	32.00	0.28
12 25 67	47.00	10.00	32.00	32.00	0.15
12 26 67	20.00	0.0	32.00	32.00	0.0
12 27 67	26.00	14.00	32.00	32.00	0.0
12 28 67	23.00	1.00	32.00	32.00	0.0
12 29 67	29.00	3.00	32.00	32.00	0.0
12 30 67	30.00	17.00	32.00	32.00	0.0
12 31 67	25.00	-13.00	32.00	32.00	0.0

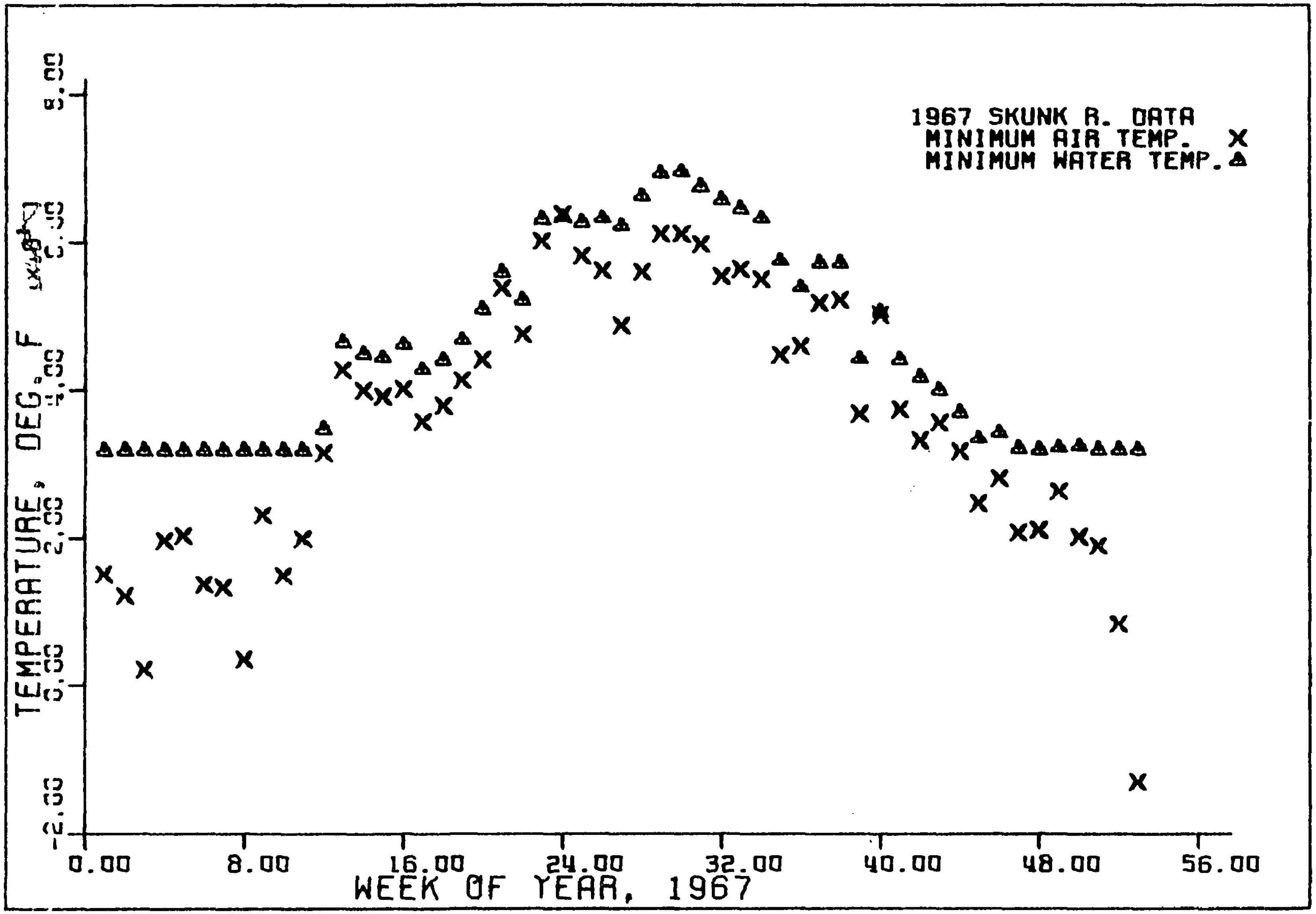
RESULTS OF WEEKLY ANALYSIS OF
AIR AND WATER TEMPERATURES AND RIVER DISCHARGES
FOR THE SKUNK RIVER AT AMES, IOWA

WEEK	BEGINNING DATE	AVERAGE HIGH AIR TEMP. DEG F	AVERAGE LOW AIR TEMP. DEG F	AVERAGE HIGH WATER TEMP. DEG F	AVERAGE LOW WATER TEMP. DEG F	AVERAGE WEEKLY Q CFS	DIFFERENCE MAXIMUM AIR-WTR DEG F	DIFFERENCE MINIMUM AIR-WTR DEG F
1	1 1 67	32.43	15.14	32.00	32.00	0.0	0.43	-16.86
2	1 8 67	31.29	12.14	32.00	32.00	0.0	-0.71	-19.86
3	1 15 67	27.43	2.14	33.57	32.00	0.02	-6.14	-29.86
4	1 22 67	40.14	19.71	33.71	32.00	3.85	6.43	-12.29
5	1 29 67	34.57	20.43	32.00	32.00	4.43	2.57	-11.57
6	2 5 67	33.71	13.86	32.00	32.00	0.00	1.71	-18.14
7	2 12 67	34.71	13.43	32.00	32.00	0.0	2.71	-18.57
8	2 19 67	24.00	3.57	32.00	32.00	0.0	-8.00	-28.43
9	2 26 67	42.57	23.14	35.14	32.00	0.0	7.43	-8.86
10	3 5 67	42.57	15.00	32.14	32.00	1.57	10.43	-17.00
11	3 12 67	41.71	20.00	32.29	32.00	14.43	9.43	-12.00
12	3 19 67	53.57	31.57	43.86	34.71	16.00	9.71	-3.14
13	3 26 67	63.00	42.71	58.43	46.57	27.29	4.57	-3.86
14	4 2 67	67.00	40.00	59.57	45.00	8.77	7.43	-5.00
15	4 9 67	58.57	39.14	58.86	44.43	13.90	-0.29	-5.29
16	4 16 67	66.86	40.29	62.14	46.29	19.00	4.71	-6.00
17	4 23 67	54.00	35.71	57.14	42.86	11.47	-3.14	-7.14
18	4 30 67	58.29	38.00	61.86	44.14	4.77	-3.57	-6.14
19	5 7 67	64.43	41.43	66.71	46.86	11.93	-2.29	-5.43
20	5 14 67	72.14	44.29	73.71	51.00	7.33	-1.57	-6.71
21	5 21 67	84.43	53.86	77.43	56.00	1.43	7.00	-2.14
22	5 28 67	65.71	47.57	66.71	52.14	6.87	-1.00	-4.57
23	6 4 67	77.29	60.29	70.57	63.14	1550.69	6.71	-2.86
24	6 11 67	80.86	63.86	70.43	63.43	2444.29	10.43	0.43
25	6 18 67	76.86	58.14	71.29	62.71	1073.57	5.57	-4.57
26	6 25 67	78.00	56.29	70.29	63.29	927.29	7.71	-7.00
27	7 2 67	75.57	48.86	70.57	62.29	238.29	5.00	-13.43

RESULTS OF WEEKLY ANALYSIS OF
AIR AND WATER TEMPERATURES AND RIVER DISCHARGES
FOR THE SKUNK RIVER AT AMES, IOWA

WEEK	BEGINNING DATE	AVERAGE HIGH AIR TEMP. DEG F	AVERAGE LOW AIR TEMP. DEG F	AVERAGE HIGH WATER TEMP. DEG F	AVERAGE LOW WATER TEMP. DEG F	AVERAGE WEEKLY Q CFS	DIFFERENCE MAXIMUM AIR-WTR DEG F	DIFFERENCE MINIMUM AIR-WTR DEG F
28	7 9 67	82.14	56.00	78.43	66.29	137.29	3.71	-10.29
29	7 16 67	85.57	61.14	82.86	69.29	56.00	2.71	-8.14
30	7 23 67	89.00	61.29	85.43	69.43	35.14	3.57	-8.14
31	7 30 67	84.43	59.86	81.29	67.57	29.00	3.14	-7.71
32	8 6 67	79.43	55.43	78.86	65.71	91.43	0.57	-10.29
33	8 13 67	83.14	56.43	78.86	64.57	27.00	4.29	-8.14
34	8 20 67	81.57	55.00	76.86	63.29	15.57	4.71	-8.29
35	8 27 67	76.14	44.71	73.00	57.43	6.59	3.14	-12.71
36	9 3 67	79.71	46.00	72.29	53.86	3.30	7.43	-7.86
37	9 10 67	75.43	51.86	69.43	57.14	6.71	6.00	-5.29
38	9 17 67	74.14	52.14	68.57	57.14	3.90	5.57	-5.00
39	9 24 67	66.57	36.86	62.00	44.29	2.93	4.57	-7.43
40	10 1 67	79.00	50.14	75.00	50.57	1.80	4.00	-0.43
41	10 8 67	57.86	37.43	55.57	44.14	4.61	2.29	-6.71
42	10 15 67	63.86	33.29	56.43	41.71	2.33	7.43	-8.43
43	10 22 67	57.43	35.57	49.86	40.00	5.06	7.57	-4.43
44	10 29 67	45.29	31.71	42.71	37.00	11.86	2.57	-5.29
45	11 5 67	47.71	24.71	43.86	33.43	4.19	3.86	-8.71
46	11 12 67	50.57	28.29	44.29	34.29	3.11	6.29	-6.00
47	11 19 67	44.86	20.86	39.14	32.14	2.63	5.71	-11.29
48	11 26 67	35.86	21.29	33.00	32.00	2.40	2.86	-10.71
49	12 3 67	45.00	26.43	34.43	32.29	4.36	10.57	-5.86
50	12 10 67	33.14	20.14	33.43	32.43	5.24	-0.29	-12.29
51	12 17 67	38.00	19.00	34.00	32.00	2.39	4.00	-13.00
52	12 24 67	30.57	8.43	32.00	32.00	0.06	-1.43	-23.57
53	12 31 67	25.00	-13.00	32.00	32.00	0.0	-7.00	-45.00


1967 SKUNK R. DATA
MAXIMUM AIR TEMP. +
MAXIMUM WATER TEMP.
TEMPERATURE, DEG. F (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
WEEK OF YEAR, 1967
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00


1967 SKUNK R. DATA
MINIMUM AIR TEMP. X
MINIMUM WATER TEMP. Δ
TEMPERATURE, DEG. F
WEEK OF YEAR, 1967
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00

C. Water and Air Temperature Data for 1968

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 68

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
1 1 68	1.00	-7.00	32.00	32.00	0.0
1 2 68	16.00	1.00	32.00	32.00	0.0
1 3 68	13.00	-12.00	32.00	32.00	0.0
1 4 68	6.00	-10.00	32.00	32.00	0.0
1 5 68	18.00	1.00	32.00	32.00	0.0
1 6 68	27.00	-10.00	32.00	32.00	0.0
1 7 68	-3.00	-20.00	32.00	32.00	0.0
1 8 68	8.00	-7.00	32.00	32.00	0.0
1 9 68	18.00	8.00	32.00	32.00	0.0
1 10 68	21.00	-2.00	32.00	32.00	0.0
1 11 68	23.00	2.00	32.00	32.00	0.0
1 12 68	22.00	18.00	32.00	32.00	0.0
1 13 68	22.00	5.00	32.00	32.00	0.0
1 14 68	19.00	4.00	32.00	32.00	0.0
1 15 68	28.00	4.00	32.00	32.00	0.0
1 16 68	25.00	-2.00	32.00	32.00	0.0
1 17 68	36.00	10.00	32.00	32.00	0.0
1 18 68	45.00	25.00	32.00	32.00	0.0
1 19 68	41.00	18.00	32.00	32.00	0.0
1 20 68	47.00	27.00	32.00	32.00	0.0
1 21 68	52.00	24.00	32.00	32.00	0.0
1 22 68	50.00	25.00	32.00	32.00	0.0
1 23 68	41.00	16.00	32.00	32.00	0.0
1 24 68	30.00	10.00	32.00	32.00	0.0
1 25 68	28.00	22.00	32.00	32.00	0.0
1 26 68	47.00	30.00	32.00	32.00	0.0
1 27 68	42.00	31.00	32.00	32.00	0.0
1 28 68	44.00	29.00	32.00	32.00	2.00
1 29 68	50.00	32.00	32.00	32.00	18.00
1 30 68	35.00	12.00	32.00	32.00	7.20
1 31 68	41.00	31.00	32.00	32.00	6.70
2 1 68	42.00	32.00	32.00	32.00	10.00
2 2 68	35.00	21.00	32.00	32.00	8.60
2 3 68	37.00	18.00	32.00	32.00	7.40
2 4 68	40.00	27.00	32.00	32.00	6.20
2 5 68	47.00	20.00	32.00	32.00	6.20
2 6 68	49.00	23.00	32.00	32.00	7.20
2 7 68	38.00	13.00	32.00	32.00	3.90
2 8 68	31.00	7.00	32.00	32.00	6.20
2 9 68	47.00	15.00	32.00	32.00	2.20
2 10 68	19.00	5.00	32.00	32.00	2.00

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 68

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
2 11 68	20.00	-5.00	32.00	32.00	1.80
2 12 68	20.00	-1.00	32.00	32.00	1.60
2 13 68	21.00	2.00	32.00	32.00	0.58
2 14 68	20.00	2.00	32.00	32.00	0.22
2 15 68	29.00	17.00	32.00	32.00	0.0
2 16 68	39.00	14.00	32.00	32.00	0.0
2 17 68	39.00	-2.00	32.00	32.00	0.0
2 18 68	22.00	-3.00	32.00	32.00	0.0
2 19 68	34.00	13.00	32.00	32.00	0.0
2 20 68	44.00	10.00	32.00	32.00	0.0
2 21 68	19.00	-8.00	32.00	32.00	0.0
2 22 68	18.00	-8.00	32.00	32.00	0.0
2 23 68	26.00	-3.00	32.00	32.00	0.0
2 24 68	35.00	14.00	35.00	32.00	0.0
2 25 68	42.00	12.00	32.00	32.00	0.0
2 26 68	34.00	28.00	32.00	32.00	0.0
2 27 68	35.00	24.00	32.00	32.00	0.0
2 28 68	35.00	22.00	32.00	32.00	0.0
2 29 68	29.00	0.0	38.00	32.00	0.0
3 1 68	28.00	9.00	39.00	32.00	0.0
3 2 68	60.00	26.00	32.00	32.00	0.0
3 3 68	31.00	8.00	36.00	32.00	0.0
3 4 68	45.00	23.00	43.00	32.00	0.0
3 5 68	63.00	38.00	37.00	32.00	0.0
3 6 68	48.00	19.00	53.00	32.00	0.0
3 7 68	53.00	22.00	46.00	32.00	0.0
3 8 68	60.00	37.00	34.00	32.00	7.80
3 9 68	51.00	39.00	36.00	32.00	76.00
3 10 68	48.00	23.00	36.00	32.00	62.00
3 11 68	38.00	23.00	39.00	32.00	52.00
3 12 68	44.00	14.00	38.00	32.00	52.00
3 13 68	33.00	10.00	39.00	32.00	38.00
3 14 68	40.00	30.00	42.00	32.00	26.00
3 15 68	57.00	24.00	43.00	32.00	19.00
3 16 68	65.00	31.00	46.00	32.00	18.00
3 17 68	67.00	34.00	45.00	37.00	19.00
3 18 68	68.00	46.00	51.00	42.00	17.00
3 19 68	65.00	37.00	53.00	41.00	18.00
3 20 68	52.00	22.00	41.00	34.00	15.00
3 21 68	35.00	21.00	42.00	32.00	13.00
3 22 68	37.00	14.00	36.00	32.00	9.20

ANALYSIS OF AIR AND WATER TEMPERATURES
FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 68

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
3 23 68	28.00	14.00	46.00	32.00	6.20
3 24 68	45.00	24.00	51.00	32.00	6.20
3 25 68	69.00	44.00	65.00	43.00	5.70
3 26 68	74.00	26.00	64.00	42.00	5.20
3 27 68	78.00	50.00	61.00	48.00	6.20
3 28 68	68.00	38.00	65.00	44.00	5.70
3 29 68	79.00	41.00	61.00	47.00	5.70
3 30 68	67.00	36.00	70.00	46.00	5.70
3 31 68	83.00	36.00	59.00	45.00	14.00
4 1 68	52.00	21.00	59.00	39.00	5.20
4 2 68	57.00	33.00	46.00	41.00	5.20
4 3 68	48.00	42.00	57.00	44.00	25.00
4 4 68	67.00	30.00	50.00	37.00	29.00
4 5 68	33.00	19.00	52.00	33.00	17.00
4 6 68	45.00	27.00	49.00	37.00	12.00
4 7 68	63.00	44.00	54.00	44.00	11.00
4 8 68	66.00	39.00	58.00	41.00	9.20
4 9 68	60.00	32.00	61.00	41.00	7.80
4 10 68	65.00	34.00	66.00	45.00	7.80
4 11 68	68.00	38.00	69.00	47.00	6.70
4 12 68	85.00	57.00	64.00	51.00	5.70
4 13 68	75.00	50.00	59.00	54.00	6.70
4 14 68	62.00	38.00	56.00	44.00	23.00
4 15 68	45.00	27.00	65.00	40.00	11.00
4 16 68	70.00	46.00	68.00	48.00	9.20
4 17 68	71.00	48.00	68.00	54.00	11.00
4 18 68	69.00	41.00	62.00	50.00	26.00
4 19 68	62.00	48.00	56.00	50.00	30.00
4 20 68	60.00	50.00	58.00	50.00	70.00
4 21 68	63.00	38.00	66.00	48.00	62.00
4 22 68	69.00	50.00	60.00	55.00	60.00
4 23 68	62.00	38.00	46.00	42.00	233.00
4 24 68	49.00	28.00	41.00	39.00	480.00
4 25 68	51.00	29.00	48.00	41.00	324.00
4 26 68	54.00	32.00	58.00	43.00	216.00
4 27 68	65.00	33.00	59.00	47.00	153.00
4 28 68	67.00	45.00	64.00	52.00	107.00
4 29 68	67.00	35.00	73.00	51.00	85.00
4 30 68	79.00	37.00	70.00	53.00	75.00
5 1 68	82.00	46.00	71.00	57.00	68.00
5 2 68	80.00	53.00	76.00	57.00	62.00

ANALYSIS OF AIR AND WATER TEMPERATURES FOR THE SKUNK RIVER AT AMES, IOWA

THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 68

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
5 3 68	89.00	53.00	71.00	58.00	58.00
5 4 68	72.00	43.00	65.00	53.00	52.00
5 5 68	60.00	31.00	68.00	49.00	48.00
5 6 68	62.00	43.00	59.00	51.00	44.00
5 7 68	67.00	51.00	54.00	51.00	48.00
5 8 68	58.00	43.00	66.00	47.00	48.00
5 9 68	72.00	42.00	61.00	50.00	44.00
5 10 68	58.00	33.00	70.00	48.00	40.00
5 11 68	68.00	42.00	65.00	54.00	38.00
5 12 68	65.00	38.00	73.00	49.00	36.00
5 13 68	72.00	47.00	69.00	55.00	38.00
5 14 68	77.00	51.00	79.00	58.00	48.00
5 15 68	81.00	50.00	79.00	60.00	44.00
5 16 68	86.00	43.00	63.00	53.00	46.00
5 17 68	58.00	37.00	69.00	51.00	46.00
5 18 68	66.00	41.00	57.00	50.00	42.00
5 19 68	49.00	41.00	65.00	47.00	44.00
5 20 68	63.00	42.00	64.00	50.00	42.00
5 21 68	64.00	36.00	67.00	50.00	38.00
5 22 68	69.00	38.00	57.00	52.00	36.00
5 23 68	59.00	47.00	68.00	51.00	36.00
5 24 68	71.00	34.00	74.00	52.00	33.00
5 25 68	70.00	50.00	62.00	55.00	36.00
5 26 68	61.00	49.00	65.00	52.00	52.00
5 27 68	54.00	45.00	66.00	50.00	52.00
5 28 68	68.00	41.00	68.00	53.00	65.00
5 29 68	73.00	46.00	62.00	50.00	92.00
5 30 68	68.00	44.00	74.00	54.00	54.00
5 31 68	74.00	52.00	63.00	60.00	54.00
6 1 68	78.00	53.00	78.00	59.00	48.00
6 2 68	80.00	52.00	80.00	60.00	40.00
6 3 68	83.00	52.00	86.00	63.00	35.00
6 4 68	91.00	62.00	89.00	68.00	26.00
6 5 68	92.00	63.00	87.00	70.00	22.00
6 6 68	92.00	66.00	87.00	71.00	19.00
6 7 68	90.00	67.00	87.00	70.00	17.00
6 8 68	91.00	66.00	90.00	70.00	16.00
6 9 68	91.00	67.00	85.00	72.00	26.00
6 10 68	93.00	62.00	87.00	72.00	94.00
6 11 68	89.00	60.00	71.00	63.00	493.00
6 12 68	76.00	55.00	71.00	62.00	129.00

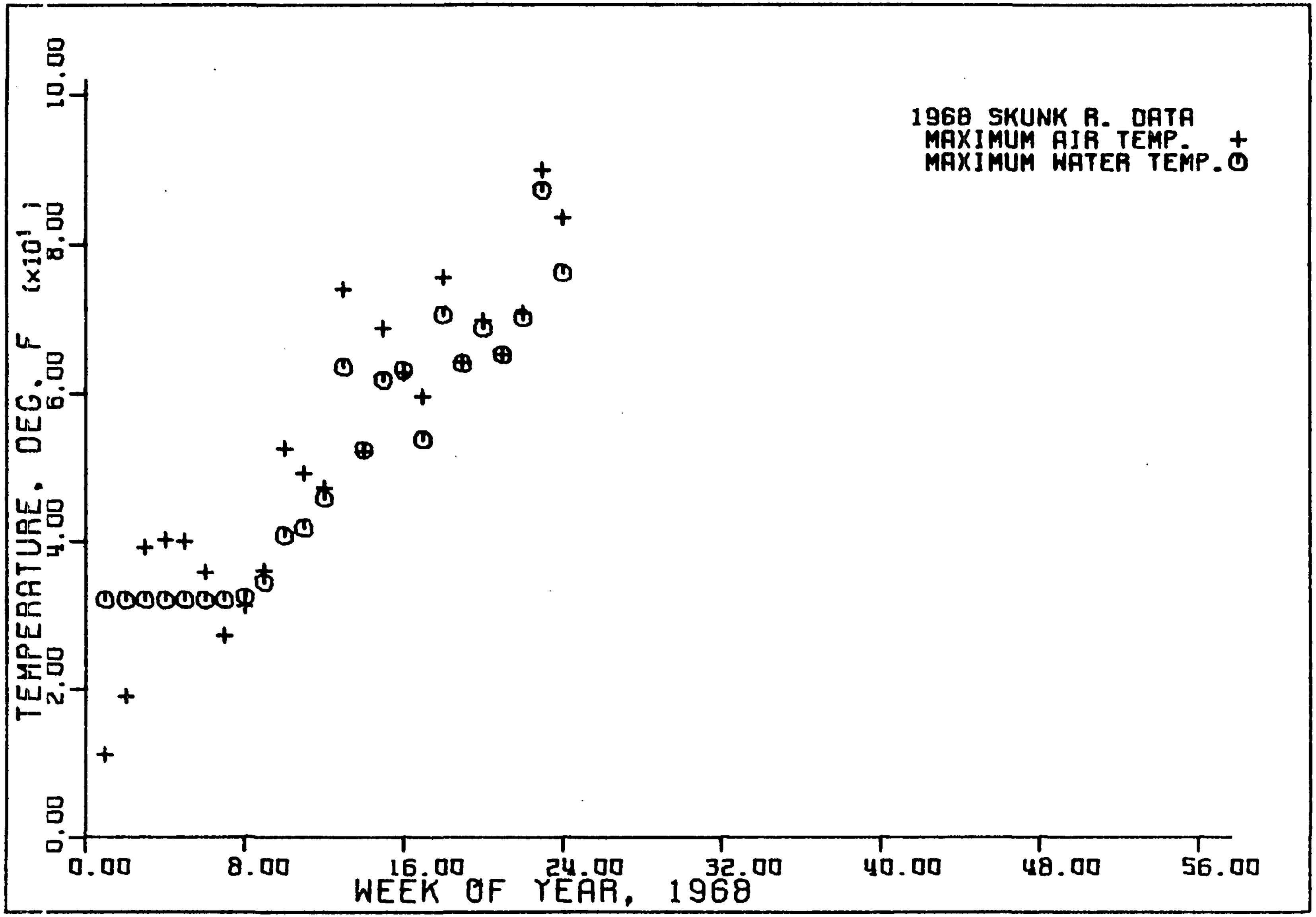
ANALYSIS OF AIR AND WATER TEMPERATURES FOR THE SKUNK RIVER AT AMES, IOWA

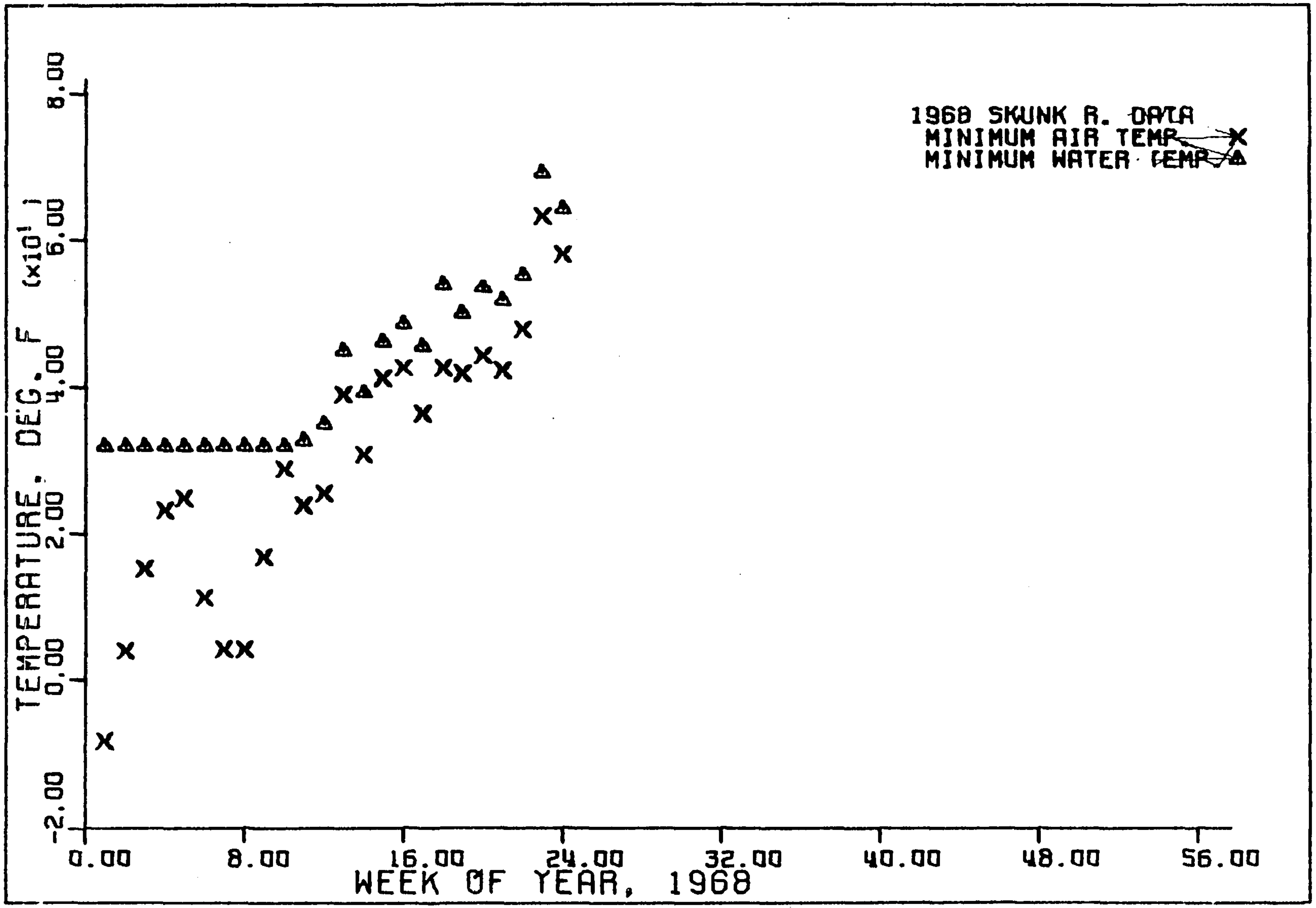
THIS ANALYSIS FOR THE YEAR BEGINNING 1 1 68

DATE	MAXIMUM AIR TEMP DEG F	MINIMUM AIR TEMP DEG F	MAXIMUM WATER TEMP DEG F	MINIMUM WATER TEMP DEG F	RIVER DISCHARGE CFS
6 13 68	75.00	51.00	79.00	62.00	52.00
6 14 68	85.00	62.00	73.00	62.00	519.00

RESULTS OF WEEKLY ANALYSIS OF
AIR AND WATER TEMPERATURES AND RIVER DISCHARGES
FOR THE SKUNK RIVER AT AMES, IOWA

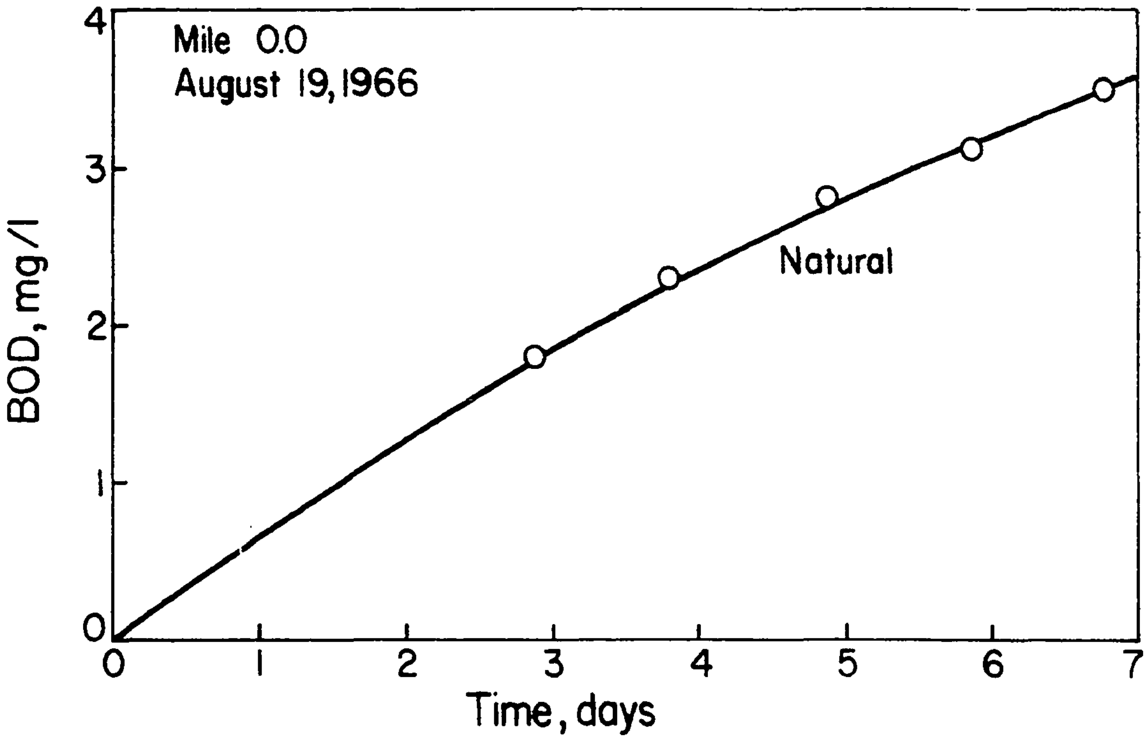
WEEK	BEGINNING DATE	AVERAGE HIGH AIR TEMP. DEG F	AVERAGE LOW AIR TEMP. DEG F	AVERAGE HIGH WATER TEMP. DEG F	AVERAGE LOW WATER TEMP. DEG F	AVERAGE WEEKLY Q CFS	DIFFERENCE MAXIMUM AIR-WTR DEG F	DIFFERENCE MINIMUM AIR-WTR DEG F
1	1 1 68	11.14	-8.14	32.00	32.00	0.0	-20.86	-40.14
2	1 8 68	19.00	4.00	32.00	32.00	0.0	-13.00	-28.00
3	1 15 68	39.14	15.14	32.00	32.00	0.0	7.14	-16.86
4	1 22 68	40.29	23.29	32.00	32.00	0.29	8.29	-8.71
5	1 29 68	40.00	24.71	32.00	32.00	9.16	8.00	-7.29
6	2 5 68	35.86	11.14	32.00	32.00	4.21	3.86	-20.86
7	2 12 68	27.14	4.14	32.00	32.00	0.34	-4.86	-27.86
8	2 19 68	31.14	4.29	32.43	32.00	0.0	-1.29	-27.71
9	2 26 68	36.00	16.71	34.43	32.00	0.0	1.57	-15.29
10	3 4 68	52.57	28.71	40.71	32.00	20.83	11.86	-3.29
11	3 11 68	49.14	23.71	41.71	32.71	32.00	7.43	-9.00
12	3 18 68	47.14	25.43	45.71	35.00	12.09	1.43	-9.57
13	3 25 68	74.00	39.00	63.57	45.00	6.89	10.43	-6.00
14	4 1 68	52.14	30.86	52.43	39.29	14.91	-0.29	-8.43
15	4 8 68	68.71	41.14	61.86	46.14	9.56	6.86	-5.00
16	4 15 68	62.86	42.57	63.29	48.57	31.31	-0.43	-6.00
17	4 22 68	59.57	36.43	53.71	45.57	224.71	5.86	-9.14
18	4 29 68	75.57	42.57	70.57	54.00	64.00	5.00	-11.43
19	5 6 68	64.29	41.71	64.00	50.00	42.57	0.29	-8.29
20	5 13 68	69.86	44.29	68.71	53.43	44.00	1.14	-9.14
21	5 20 68	65.29	42.29	65.29	51.71	39.00	0.0	-9.43
22	5 27 68	70.71	47.71	70.14	55.14	57.86	0.57	-7.43
23	6 3 68	90.00	63.29	87.29	69.14	23.00	2.71	-5.86
24	6 10 68	83.60	58.00	76.20	64.20	257.40	7.40	-6.20

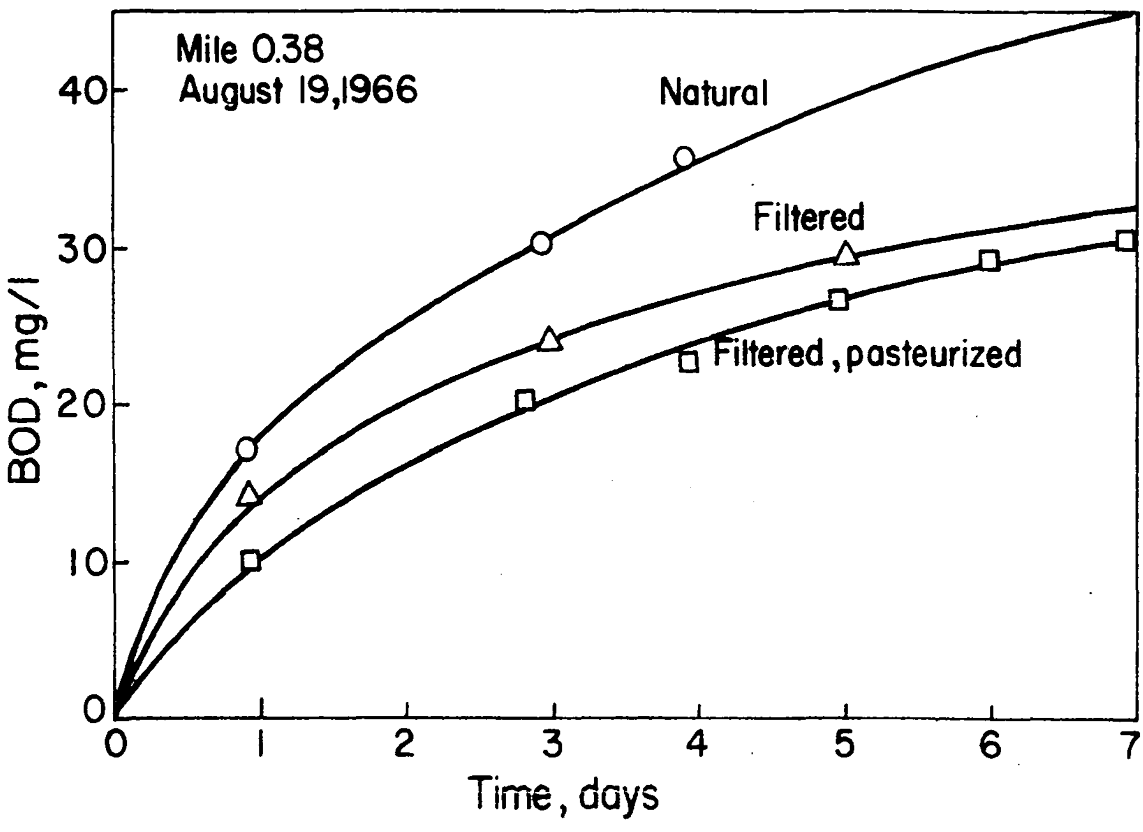

1968 SKUNK R. DATA
MAXIMUM AIR TEMP. +
MAXIMUM WATER TEMP. ⊙
TEMPERATURE, DEG. F (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
WEEK OF YEAR, 1968

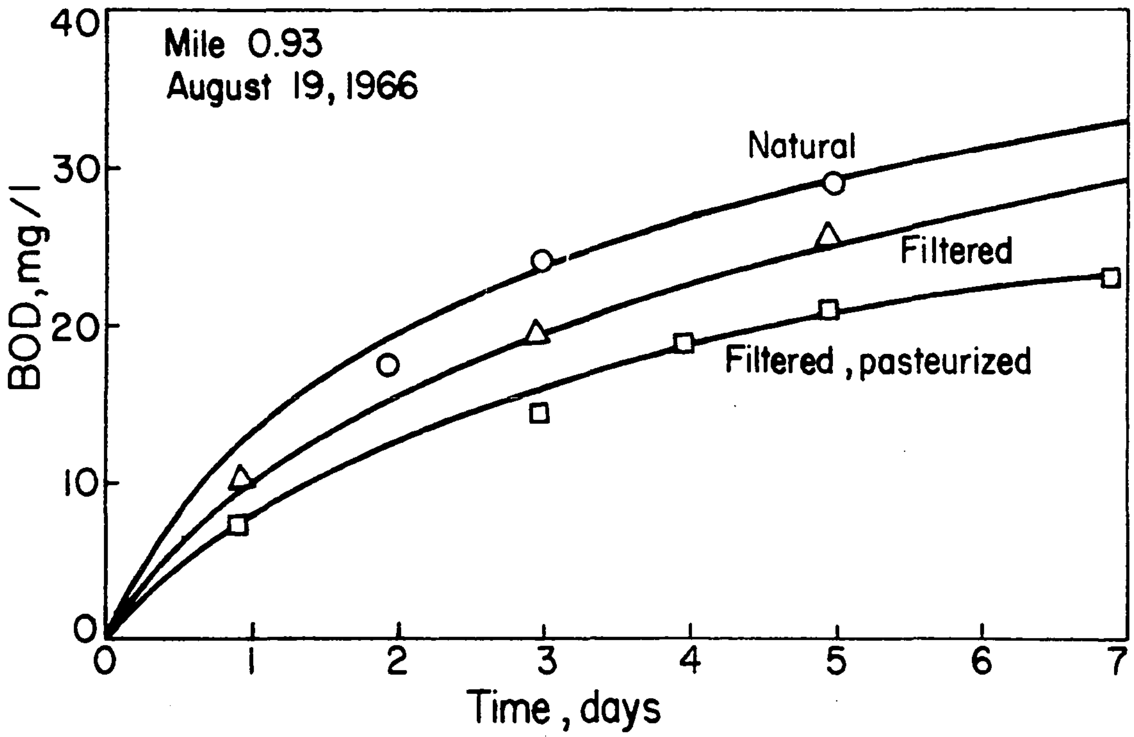

1968 SKUNK R. DATA
MINIMUM AIR TEMP. X
MINIMUM WATER TEMP. Δ
TEMPERATURE, DEG. F (x10¹)
-2.00
0.00
2.00
4.00
6.00
8.00
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
WEEK OF YEAR, 1968

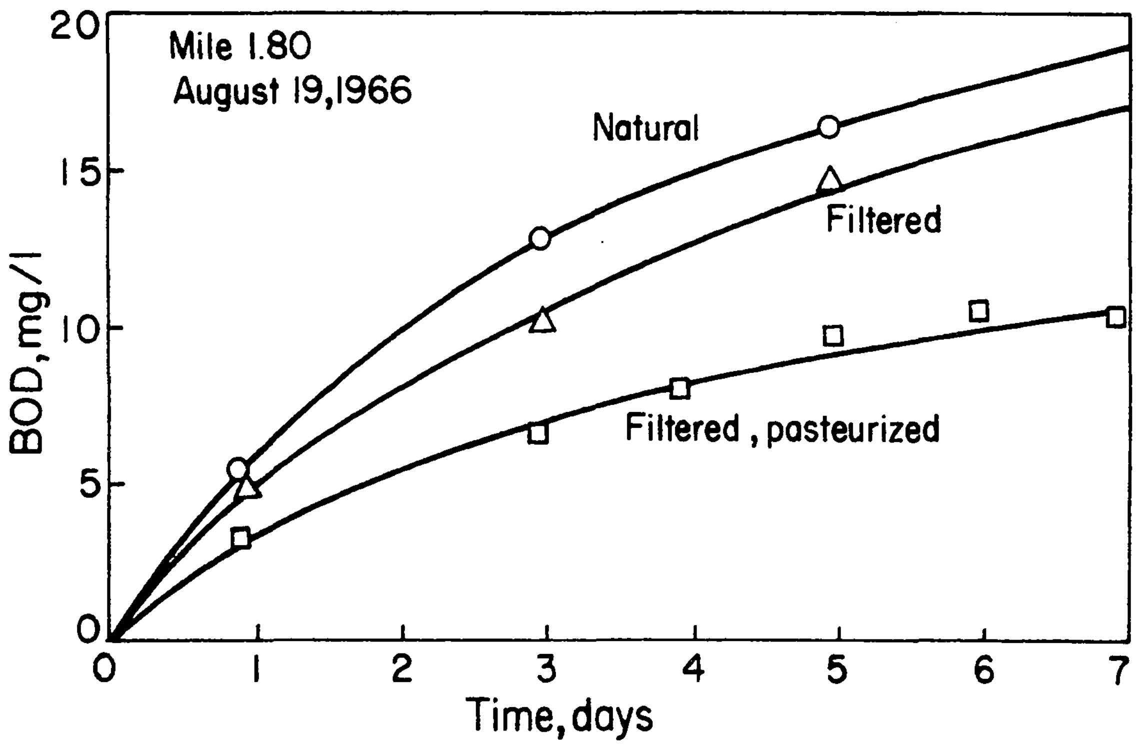
XXI. APPENDIX D

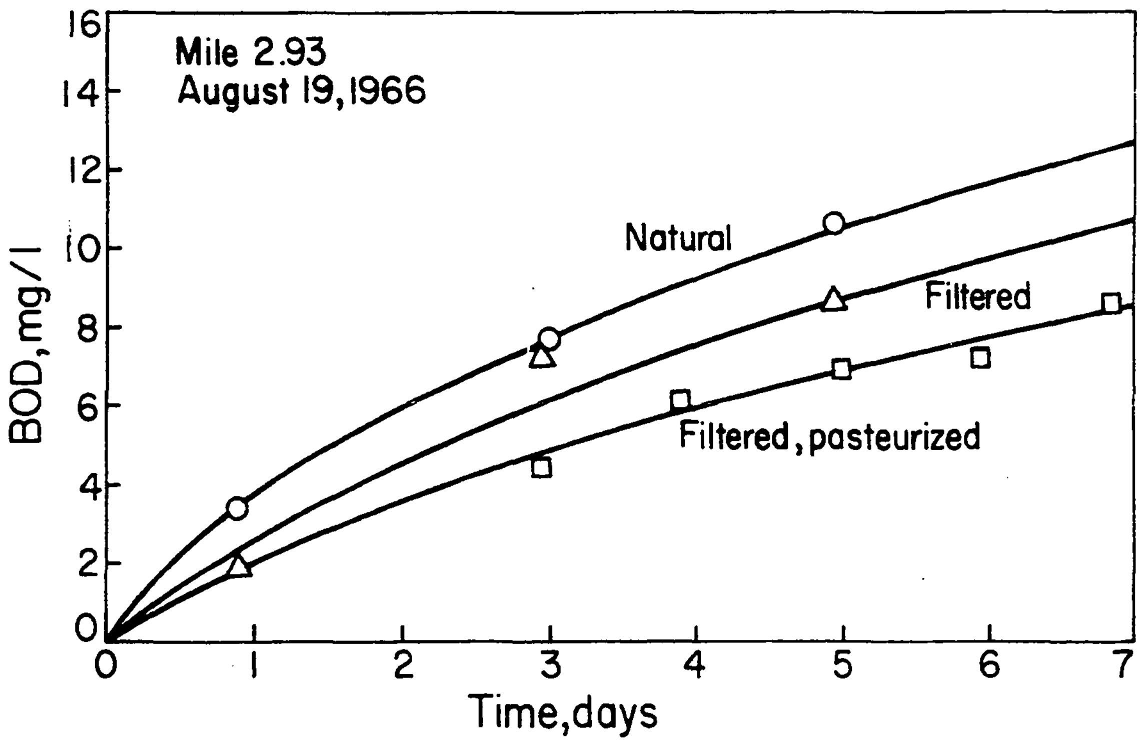
A. Biochemical Oxygen Demand Relationships, August 17-19, 1966

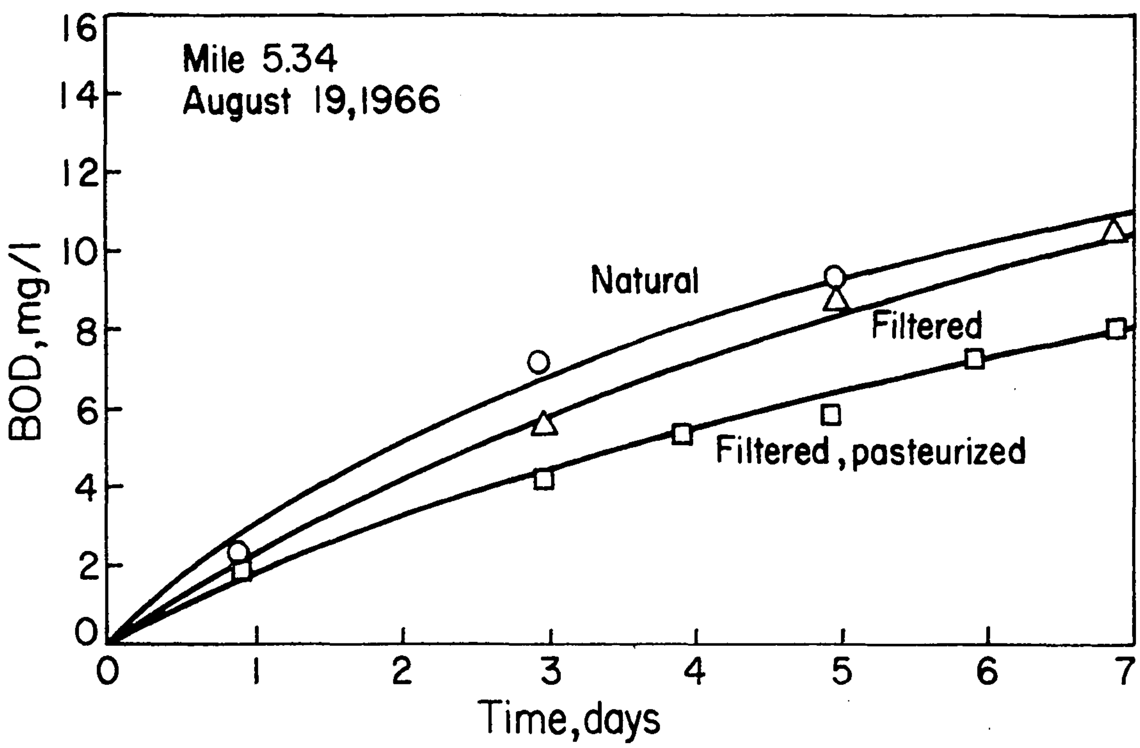

Mile 0.0
August 19, 1966
Natural
BOD, mg/l
Time, days
0
1
2
3
4
5
6
7

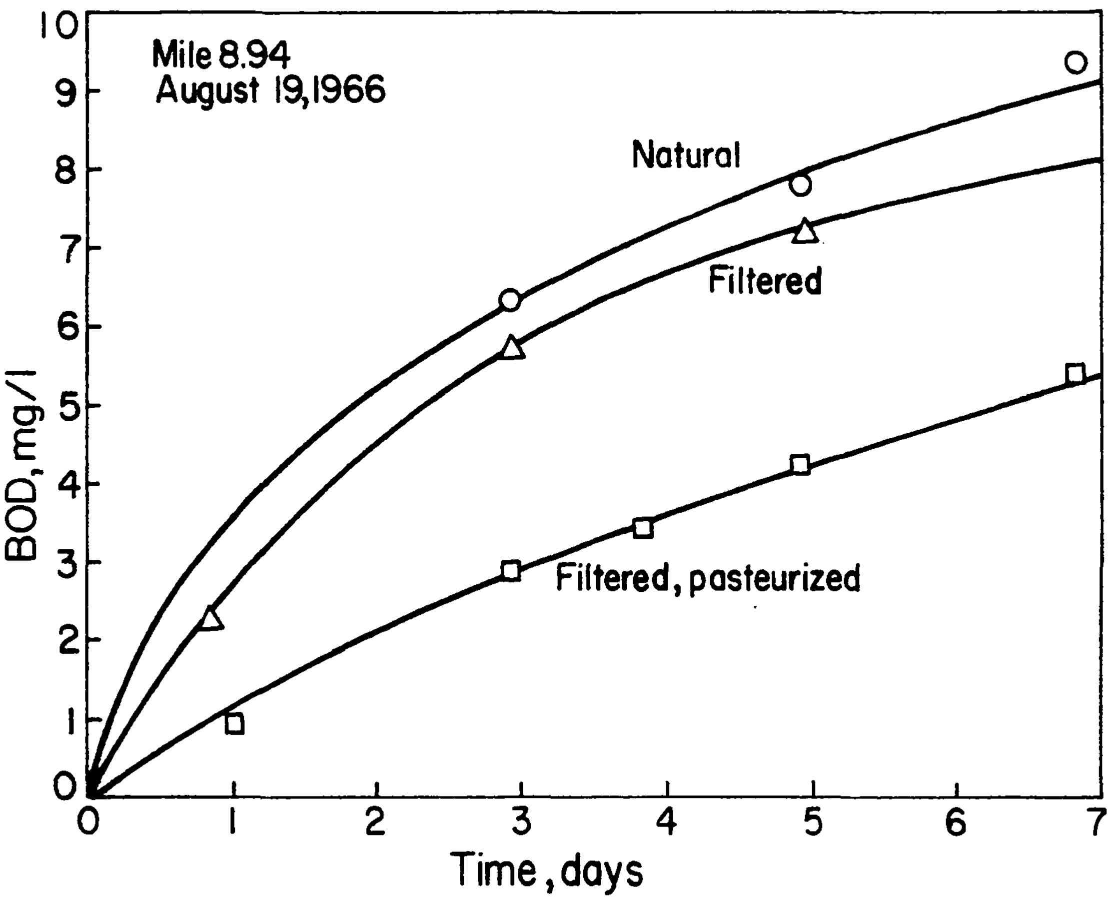

Mile 0.38
August 19, 1966
Natural
Filtered
Filtered, pasteurized
BOD, mg/l
Time, days
0
10
20
30
40
1
2
3
4
5
6
7


Mile 0.93
August 19, 1966
Natural
Filtered
Filtered, pasteurized
BOD, mg/l
Time, days
0
10
20
30
40
0
1
2
3
4
5
6
7


Mile 1.80
August 19, 1966
Natural
Filtered
Filtered, pasteurized
BOD, mg/l
Time, days
0
5
10
15
20
0
1
2
3
4
5
6
7

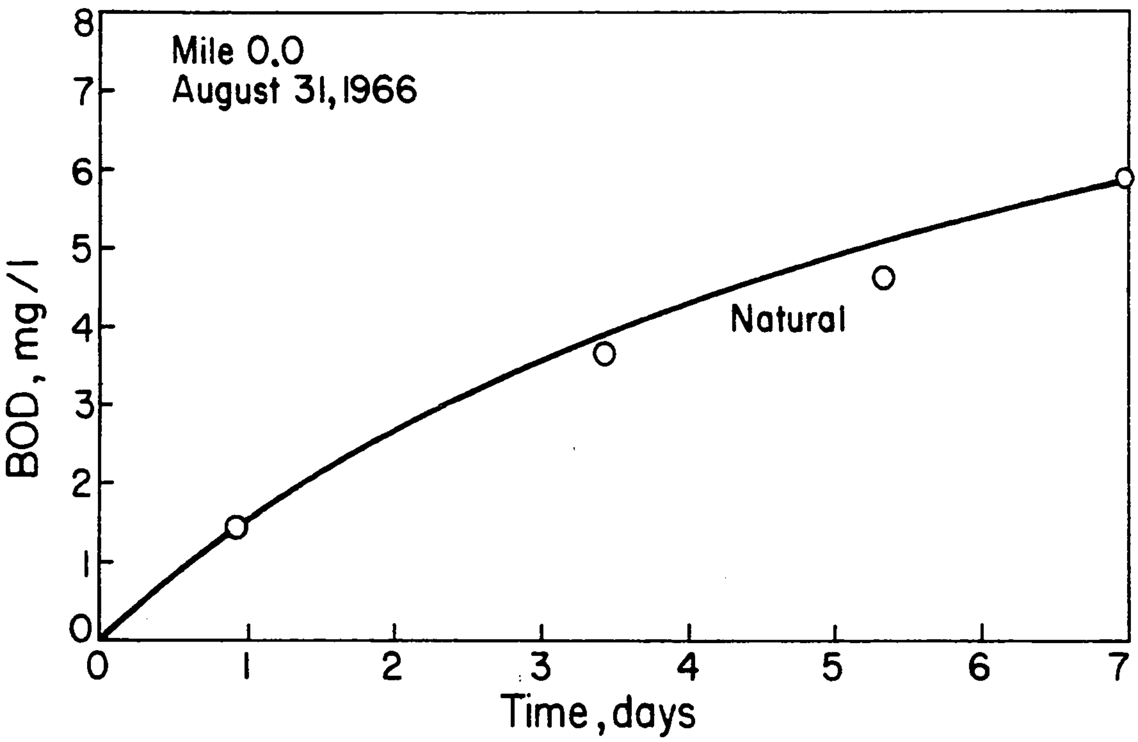

Mile 2.93
August 19,1966
BOD, mg/l
Time, days
Natural
Filtered
Filtered, pasteurized
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7

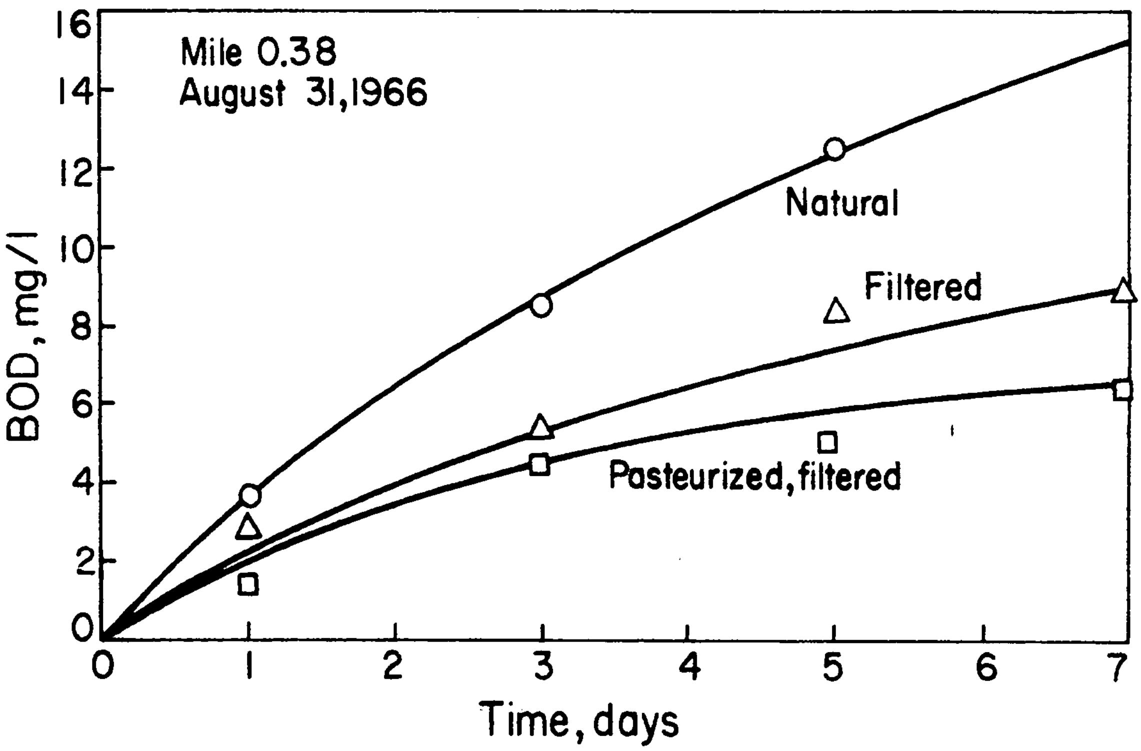

Mile 5.34
August 19,1966
BOD, mg/l
Time, days
Natural
Filtered
Filtered, pasteurized
0
2
4
6
8
10
12
14
16
0
1
2
3
4
5
6
7

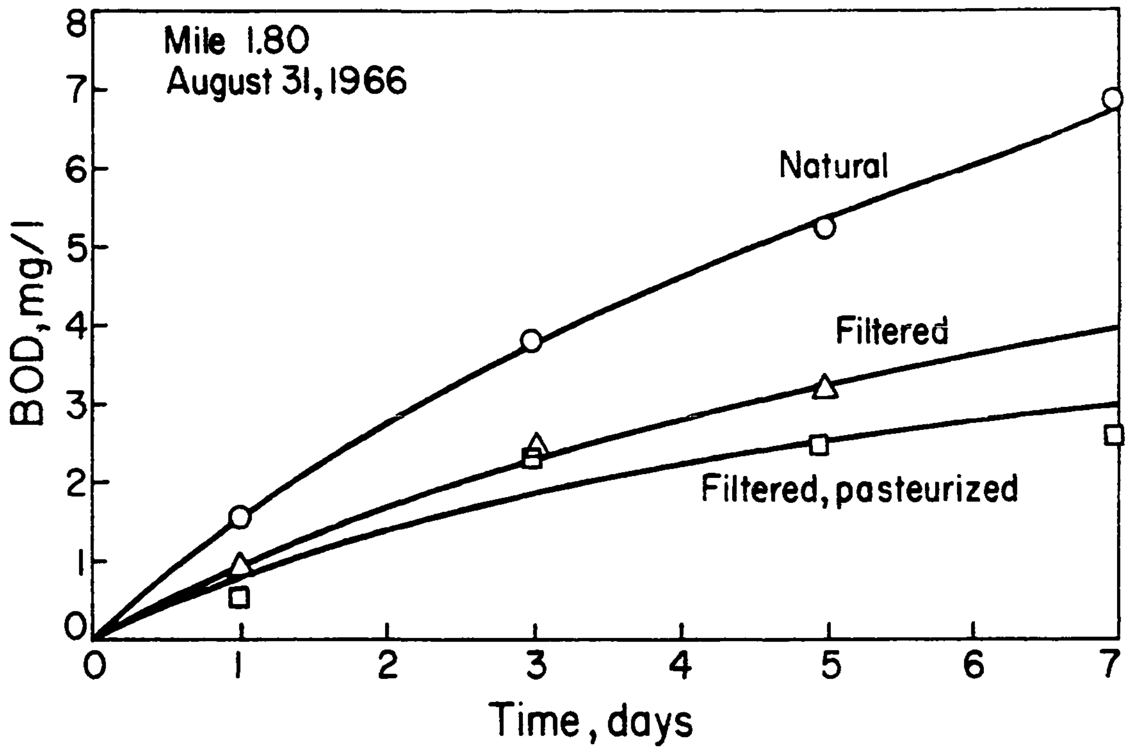


Mile 8.94
August 19,1966
Natural
Filtered
Filtered, pasteurized
BOD, mg/l
Time, days
0
1
2
3
4
5
6
7
8
9
10

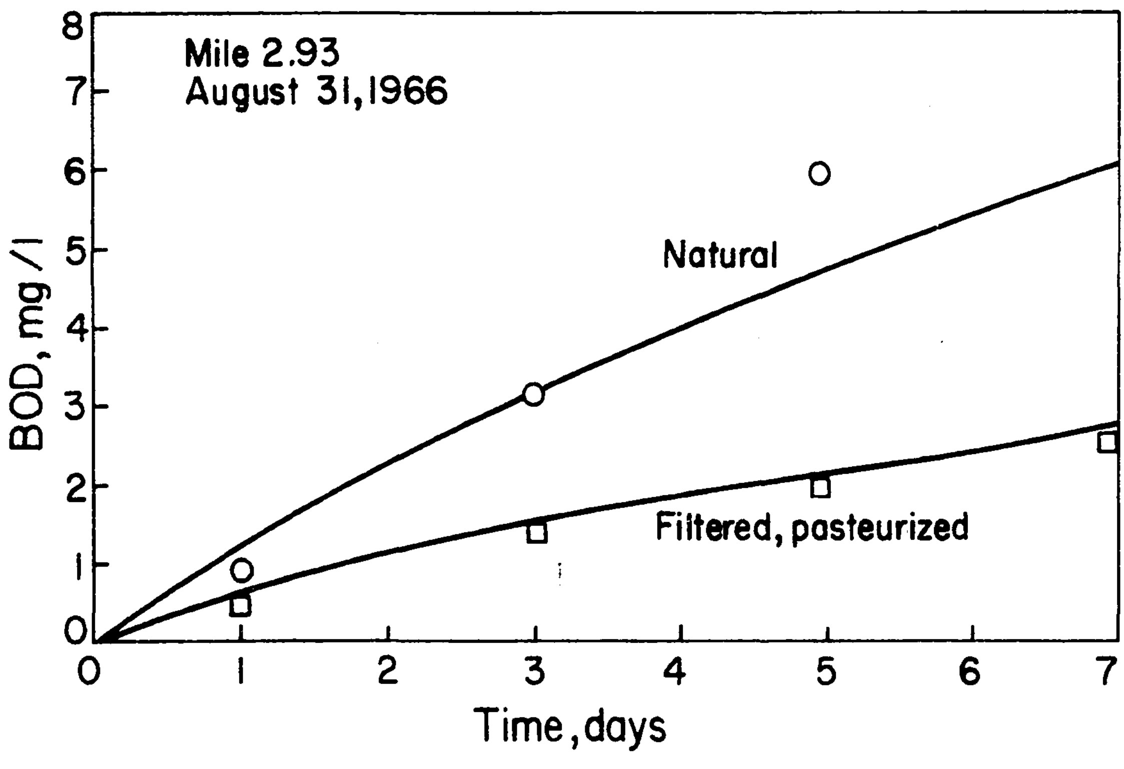
B. Biochemical Oxygen Demand Relationships, August 30-31, 1966


Mile 0.0
August 31, 1966
Natural
BOD, mg/l
Time, days
0
1
2
3
4
5
6
7
8

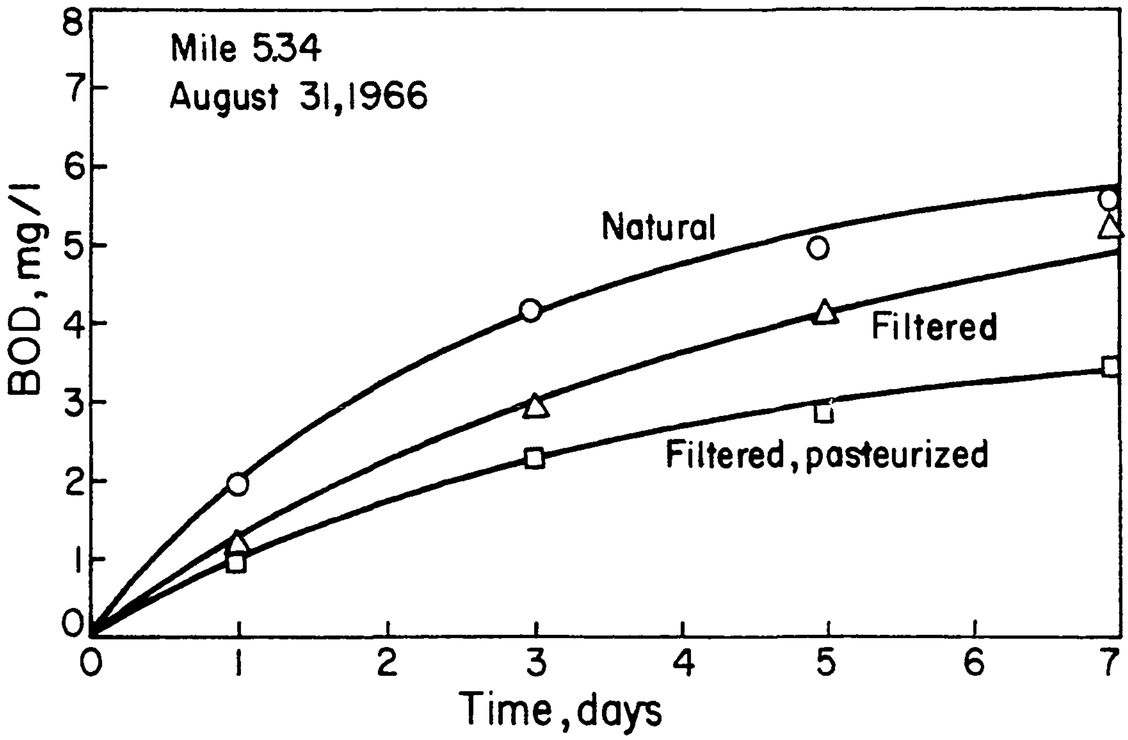

Mile 0.38
August 31, 1966
Natural
Filtered
Pasteurized, filtered
BOD, mg/l
Time, days
0
2
4
6
8
10
12
14
16
1
3
5
7

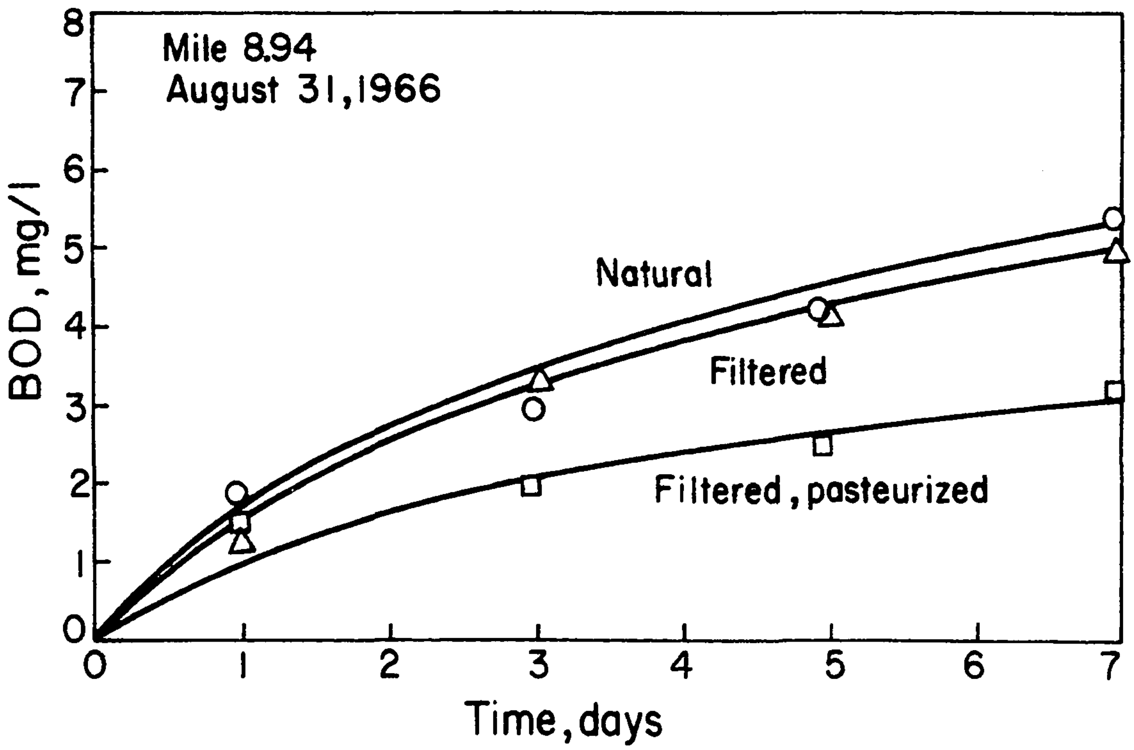


Mile 1.80
August 31, 1966
Natural
Filtered
Filtered, pasteurized
BOD, mg/l
Time, days
0
1
2
3
4
5
6
7
8

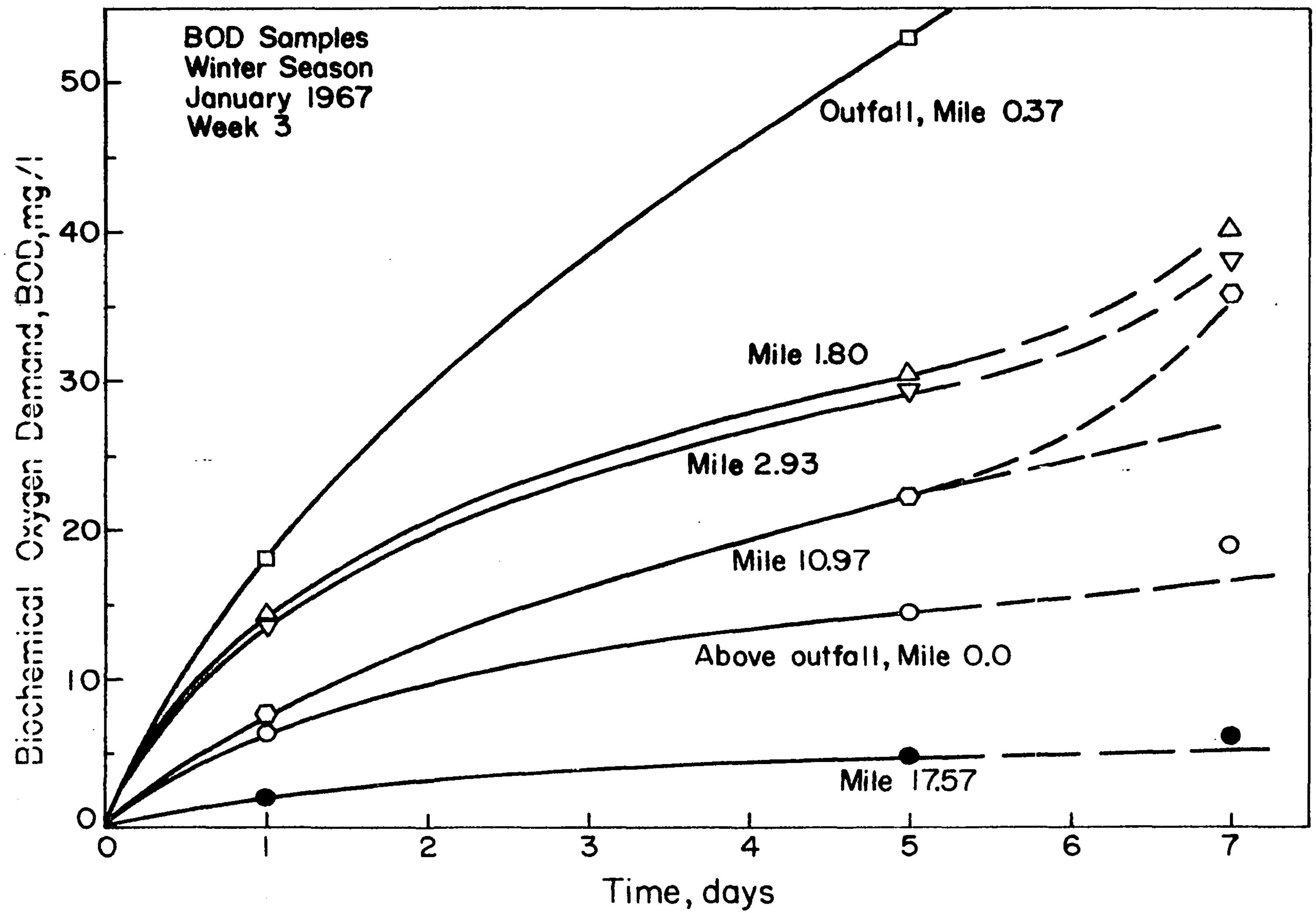


Mile 2.93
August 31, 1966
Natural
Filtered, pasteurized
BOD, mg/l
Time, days
0
1
2
3
4
5
6
7
8

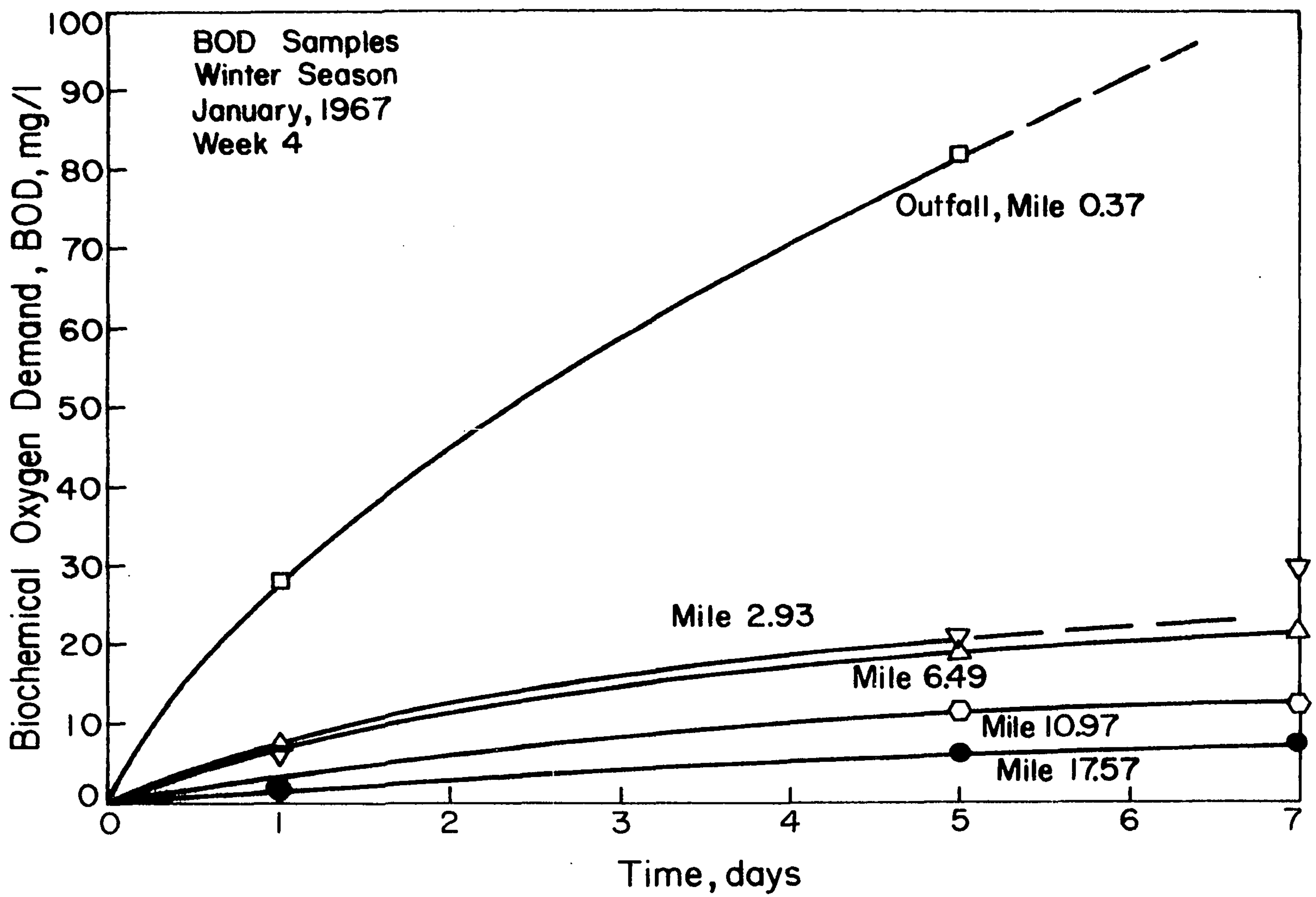

Mile 5.34
August 31, 1966
Natural
Filtered
Filtered, pasteurized
BOD, mg/l
Time, days
0
1
2
3
4
5
6
7
8


Mile 8.94
August 31, 1966
Natural
Filtered
Filtered, pasteurized
BOD, mg/l
Time, days
0
1
2
3
4
5
6
7
8

C. Biochemical Oxygen Demand Relationships, Winter Season, 1966



BOD Samples
Winter Season
January 1967
Week 3
Outfall, Mile 0.37
Mile 1.80
Mile 2.93
Mile 10.97
Above outfall, Mile 0.0
Mile 17.57
Biochemical Oxygen Demand, BOD, mg/l
Time, days
0
1
2
3
4
5
6
7
10
20
30
40
50


BOD Samples
Winter Season
January, 1967
Week 4
Biochemical Oxygen Demand, BOD, mg/l
Time, days
Outfall, Mile 0.37
Mile 2.93
Mile 6.49
Mile 10.97
Mile 17.57
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7

D. Dissolved Oxygen and Temperature Relationships, Fall Season, 1966

Table D-1. Diurnal values of temperature and dissolved oxygen in the Skunk River, October 6 and 7, 1966

	Mile 0.0			Mile 0.36 and 0.38					Mile 1.0		
Line	Time CST	Temperature deg C	DO mg/l	Time CST	Temperature deg C	DO mg/l	Temperature deg C	DO mg/l	Time CST	Temperature deg C	DO mg/l
1	0610	7.5	5.9	0630	6.4	7.0	14.2	2.0	—	—	—
2	0800	6.7	6.1	0810	6.2	8.3	15.5	2.2	0930	12.5	0.1
3	1005	8.8	9.1	1010	9.2	12.4	17.8	2.0	1130	14.8	0.3
4	1205	14.0	11.6	1210	16.0	14.8	19.3	1.4	—	—	—
5	1405	18.8	11.7	1415	20.0	14.6	19.8	1.1	1535	21.5	0.0
6	1610	17.5	10.3	1620	19.2	13.4	19.7	0.4	—	—	—
7	1805	14.8	8.1	1815	15.1	10.2	19.5	0.2	1935	17.5	0.0
8	2005	13.8	6.1	2025	13.9	5.8	19.3	0.4	—	—	—
9	2210	12.2	5.7	2220	11.3	5.8	19.0	0.3	2345	16.5	0.0
10	0015	11.0	5.8	0025	10.7	6.0	18.9	0.7	—	—	—
11	0220	10.2	5.3	0240	10.2	5.9	18.9	0.9	—	—	—
12	0410	9.8	5.6	0420	9.8	5.9	18.5	1.0	—	—	—
13	0615	9.4	6.7	0625	9.2	6.0	17.0	1.7	0740	14.5	0.0

Table D-1. Cont.

Time CST	Mile 1.8 Temperature deg C	DO mg/1	Time CST	Mile 2.9 Temperature deg C	DO mg/1	Time CST	Mile 6.5 Temperature deg C	DO mg/1	Time CST	Mile 11.0 Temperature deg C	DO mg/1
0645	10.2	0.1	0700	10.0	0.2	0710	7.4	3.2	0730	7.1	6.2
0825	9.5	0.4	0840	8.6	0.4	0850	7.5	4.6	0905	7.2	8.0
1030	11.4	2.0	1040	11.0	4.3	1050	11.0	8.9	1105	10.5	11.4
1230	16.0	3.6	1240	14.6	7.6	1255	15.8	12.8	1305	15.0	13.4
1430	20.0	4.3	1445	17.5	9.5	1500	18.8	13.1	1510	17.7	14.3
1640	19.6	2.0	1650	18.0	7.7	1705	18.1	12.3	1720	17.0	12.2
1830	17.2	0.0	1845	17.2	2.4	1850	16.0	8.6	1910	15.1	8.6
2040	15.2	0.0	2055	15.8	0.1	2110	14.0	4.4	2125	14.5	6.2
2235	14.3	0.0	2250	14.2	0.1	2300	13.0	3.4	2315	13.0	5.5
0035	14.0	0.0	0050	13.0	0.0	0100	12.2	3.1	0115	12.0	3.8
0250	13.7	0.0	0300	12.8	0.0	0315	11.9	3.2	0330	11.4	5.4
0440	13.5	0.0	0450	12.0	0.0	0505	11.0	2.9	0520	11.0	5.5
0640	12.8	0.0	0650	11.2	0.0	0700	10.5	2.6	1715	10.2	5.6

Table D-2. Diurnal values of temperature and dissolved oxygen in the Skunk River, October 24 and 25, 1966.

	Mile 0.0			Mile 0.4			Mile 3.0			Mile 6.5			Mile 10.97		
Line	Time CST	Temperature deg C	DO mg/l	Time CST	Temperature deg C	DO mg/l	Time CST	Temperature deg C	DO mg/l	Time CST	Temperature deg C	DO mg/l	Time CST	Temperature deg C	DO mg/l
1	0615	4.8	7.1	0620	19.2	1.7	0630	8.2	0.1	0645	5.7	2.2	0700	4.6	5.0
2	0815	4.4	7.6	0820	19.2	1.6	1835	7.6	0.6	0845	5.0	2.9	0900	4.5	6.0
3	1015	5.7	9.6	1020	19.9	1.6	1030	9.4	1.7	1045	8.0	7.7	1100	6.9	8.9
4	1215	15.6	7.9	1220	21.0	0.7	1235	12.4	2.9	1250	12.9	13.2	1300	10.0	11.9
5	1425	14.0	11.6	1430	21.8	0.6	1440	15.0	3.7	1455	15.2	15.4	1605	13.7	13.8
6	1625	16.8	11.9	1630	21.1	0.5	1650	15.1	2.6	1700	14.0	13.6	1715	12.9	12.1
7	1815	12.3	7.8	1820	21.0	0.7	1825	13.9	0.0	1835	12.2	6.7	1850	11.3	8.4
8	2000	10.2	5.5	2005	20.9	1.0	2025	13.5	0.0	2040	10.2	2.8	2055	10.3	6.9
9	2200	8.0	5.4	2205	20.1	0.7	2220	12.0	0.0	2235	8.0	2.1	2250	8.8	5.8
10	0015	6.0	6.2	0020	20.0	1.0	0035	10.4	0.0	0045	7.8	2.1	0105	7.2	5.2
11	0215	5.7	6.4	0220	19.6	1.5	0235	9.2	0.2	0245	6.7	3.0	0300	6.6	5.0
12	0410	4.4	6.6	0415	19.6	1.7	0420	8.4	0.2	0435	6.3	1.6	0445	5.4	3.4
13	0600	4.9	6.6	0605	18.8	1.9	0615	8.0	0.1	0630	5.8	1.4	0640	5.0	5.1

XXII. APPENDIX E

A. FORTRAN IV Source Listing for the ISU Water Quality Model

```
C     **
C     **                 ISU WATER QUALITY MODEL
C     **  MATHEMATICAL MODEL FOR RIVER WATER-QUALITY STUDIES
C     **       SKUNK RIVER DOWNSTREAM OF AMES, IOWA
C     **                 IOWA STATE UNIVERSITY
C     **              SANITARY ENGINEERING SECTION
C     **                                 M D DOUGAL  1968
C     **
      REAL KDFCT(3,100),KNFCT(3,100),KNTFCT(3,100),KPFCT(3,100),
     1 K2RX(3,100),LAAMN(3,100),LACBN(3,100),LATX(3,100),LABL(3,100),
     2 NITRX(3,100),LAERM(3,100),KNR,K2R,KPOR,KNTR,KCOLI,KCTBR,
     3 K2ER,KKNTR,KKDE,KKDR,KKDRLB,KKNR,KKPOR,KETBR,KKCOL,
     4 KKCOLX,KKPOX,KKDRX,KKNTX,KKNRX,LAE,LAR,LAAMNU,LABLU,
     5 LAERMU,NITRXU,NITRE,NITRR,KDE,KDR,KDRLB,K2ICE
      DIMENSION AMNRM(3,100),COLFCT(3,100),COLIX(3,100),BLP(3,100),
     1 PO4RX(3,100),QRX(3,100),TIMX(3,100),TEMPRX(3,100),XMI(3,100),
     2 DORX(3,100),DODEF(3,100),ALGRX(3,100),ALFCT(3,100),
     3 BEFCT(3,100),DELDEF(3,100),ALGTP(15),EFFL(15),RQVD(15),
     4 RWQD(15),IDENT1(15),IDENT2(15),ISESON(2),DOMN(3),XSAV(3),
     5 XMI1(100),XMI2(100),XMI3(100),DOR1(100),DOR2(100),
     6 DOR3(100),YBOD(100),ZBOD(100),AAMN(100),TSAV(3),DORG(2),
     7 XLAB(5),YLAB(5),GLAB(5),DATLAB(5),DL2(5),DL3(5),
     8 WLAB(5),ZLAB(5),BLAB(5),DAZLAB(5),DL4(5),DL5(5)
      WRITE(3,200)
    1 ICOUNT = 0
      ICHECK=1
      XGAGE=0.0
C     **
C     **  INITIALIZE ARRAYS FOR BASIC DATA INPUT
C     **
      DO 2 I=1,15
      EFFL(I)=0.0
      RWQD(I)=0.0
      RQVD(I)=0.0
    2 ALGTP(I)=0.0
C     **
C     **  READ IN EFFLUENT AND RIVER DATA
```

```
C      **
       READ(1,101)KTYPE,IDENT1
       IF(KTYPE.NE.1) GO TO 90
       READ(1,102)KTYPE,IDENT2,ISESON
       IF(KTYPE.NE.2) GO TO 90
       READ(1,103)KTYPE,EFFL
       IF(KTYPE.NE.3) GO TO 90
       READ(1,103)KTYPE,RWQD
       IF(KTYPE.NE.4) GO TO 90
       READ(1,103)KTYPE,RQVD
       IF(KTYPE.NE.5) GO TO 90
       READ(1,103)KTYPE,ALGTP
       IF(KTYPE.NE.6) GO TO 90
       READ(1,104)KTYPE,IBLCY,DBLCY,IDQCY,DLQCY,ILGCY,DPMR,IWTRA,
      1 IPNCH,IWRIT,IPLOT,NLIN
       IF(KTYPE.NE.7) GO TO 90
C      **
C      **  TRANSFER INPUT DATA TO VARIABLE NAMES
C      **
       QEMGD=EFFL(1)
       TEMPE=EFFL(2)
       PCSE =EFFL(3)
       BODE =EFFL(5)
       KDE  =EFFL(6)
       LAE  =EFFL(7)
       AMNE =EFFL(8)
       NITRE=EFFL(9)
       PO4E =EFFL(10)
       COLIE=EFFL(11)
       GAMMA1=EFFL(14)
       GAMMA2=EFFL(15)
       TMPRD=RWQD(1)
       TMPRN=RWQD(2)
       PCSRD=RWQD(3)
       PCSRN=RWQD(4)
       BODR =RWQD(5)
       KDRLB=RWQD(6)
```

```
LAR  =RWQD(7)
AMNR =RWQD(8)
NITRR=RWQD(9)
PO4R =RWQD(10)
COLIR=RWQD(11)
BLX  =RWQD(12)
DBLX =RWQD(13)
ALPHA=RWQD(14)
BETA =RWQD(15)
QRCFS=RQVD(1)
DELQX=RQVD(2)
PSDQD=RQVD(3)
PSDQN=RQVD(4)
CVA  =RQVD(5)
CVB  =RQVD(6)
XIN  =RQVD(7)
TIMIN=RQVD(8)
TIMFN=RQVD(9)
DTIM =RQVD(10)
KCOLI=RQVD(11)
KPOR =RQVD(12)
KNTR =RQVD(13)
KNR  =RQVD(14)
KDR  =RQVD(15)
TPBRD=ALGTP(1)
TPBRN=ALGTP(2)
KCTBR=ALGTP(3)
TMPAD=ALGTP(4)
TMPAN=ALGTP(5)
CAALG=ALGTP(6)
CBALG=ALGTP(7)
TAUTM=ALGTP(8)
PMR  =ALGTP(9)
PRRIN=ALGTP(10)
PRRMX=ALGTP(11)
BODDQ=ALGTP(12)
DOFSH=ALGTP(13)
```

```
      K2ICE=ALGTP(14)
      K2R  =ALGTP(15)
C     **
C     **  CHECK ON SPAN OF TIME INCREMENTS***LIMIT IS 100 INCREMENTS
C     **
    4 CONTINUE
      QECFS = QEMGD/0.646
      QRXIN = QECFS+QRCFS
      IF(DTIM.LE.0) GO TO 89
      NT=((TIMFN-TIMIN)/DTIM)
      IF(NT.LE.100) GO TO 5
      NT=100
    5 CONTINUE
      IF(GAMMA1.GT.0.0) GO TO 7
      WRITE(3,206)GAMMA2
      GO TO 1
    7 IF(GAMMA2.GT.0.0) GO TO 8
      WRITE(3,206)GAMMA1
    8 CONTINUE
C     **
C     **  WRITE OUT INPUT DATA AS ECHO CHECK
C     **       WRITE OUT CYCLE NUMBER AND GAMMA VALUES
C     **
      WRITE(3,210)IDENT1,IDENT2,ISESON
      WRITE(3,211)EFFL
      WRITE(3,212)RWQD
      WRITE(3,213)RQVD
      WRITE(3,214)ALGTP
      WRITE(3,215)IBLCY,DBLCY,IDQCY,DLQCY,ILGCY,DPMR,IWTRA,
     1 IPNCH,IWRIT,IPLOT,NLIN
      WRITE(3,210)IDENT1,IDENT2,ISESON
      WRITE(3,230)GAMMA1,GAMMA2
      WRITE(3,231)ICHECK,BLX,DBLCY,DBLX,DOFSH,QECFS,QRCFS,QRXIN,
     1 DLQCY,PMR,DPMR
C     **
C     **  INITIALIZE OUTPUT ARRAYS
C     **
```

```
      DO 10 JJ=1,3
      TSAV(JJ)=0.0
      XSAV(JJ)=0.0
      DOMN(JJ)=0.0
   10 CONTINUE
      DO 12 ID=1,3
      DO 12 J=1,100
      TIMX(ID,J)=0.0
      XMI(ID,J)=0.0
      TEMPRX(ID,J)=0.0
      QRX(ID,J)=0.0
      LAERM(ID,J)=0.0
      LABL(ID,J)=0.0
      LACBN(ID,J)=0.0
      LAAMN(ID,J)=0.0
      LATX(ID,J)=0.0
      AMNRM(ID,J)=0.0
      COLIX(ID,J)=0.0
      PO4RX(ID,J)=0.0
      NITRX(ID,J)=0.0
      KDFCT(ID,J)=0.0
      KNFCT(ID,J)=0.0
      K2RX(ID,J)=0.0
      BLP(ID,J)=0.0
      KPFCT(ID,J)=0.0
      KNTFCT(ID,J)=0.0
      COLFCT(ID,J)=0.0
      DORX(ID,J)=0.0
      DODEF(ID,J)=0.0
      ALFCT(ID,J)=0.0
      BEFCT(ID,J)=0.0
      ALGRX(ID,J)=0.0
      DELDEF(ID,J)=0.0
   12 CONTINUE
      DO 13 M=1,100
      XMI1(M) = 0.0
      XMI2(M) = 0.0
```

```
      XMI3(M) = 0.0
      DOR1(M) = 0.0
      DOR2(M) = 0.0
      DOR3(M) = 0.0
      YBOD(M) = 0.0
      ZBOD(M) = 0.0
   13 AAMN(M) = 0.0
C     **
C     **  ANALYZE INPUT DATA FOR INITIAL RELATIONSHIPS
C     **       TO BE COMPUTED AT THE BEGINNING OF THE ASSIMILATIVE REACH
C     **            DETERMINE OXYGEN DEMAND OF AMMONIA,
C     **            ULTIMATE BOD VALUES IF NEEDED,
C     **            RIVER DATA FOR CLEAN STREAM ENVIRONMENT
C     **            USING ALPHA AND BETA FACTORS IF APPLIED
C     **
      IF(QRXIN.LE.0.0) GO TO 89
      UX = CVA*QRXIN**CVB
      DELX = UX*24.0*DTIM
      DELQT = DELX*DELQX
C     **
C     **  CONVERT ALL COEFFICIENTS FROM BASE 10 TO BASE E
C     **
      KKCOL=2.3*KCOLI
      KKDE= 2.3*KDE
      KKDRLB=2.3*KDRLB
      KKNR= 2.3*KNR
      KKNTR=2.3*KNTR
      KKPOR=2.3*KPOR
      KETBR=2.3*KCTBR
C     **
C     ** IF REQUESTED, COMPUTE RIVER K1 VALUE AND
C     **   GAGING STATION BOD DATA
C     **
      S1BOD = (BODE*QECFS+BODR*QRCFS)/QRXIN
      S1BLP = (4.45*BLX*DTIM*UX)/QRXIN
      BODAME = 4.56*AMNE*BETA
      BODAMR = 4.56*AMNR*BETA
```

```
      S1AMLA = (BODAME*QECFS+BODAMR*QRCFS)/QRXIN
      IF(GAMMA2.GE.1.0) GO TO 15
      S1AMB5 = GAMMA2*S1AMLA
      GO TO 16
   15 S1AMB5 = 0.60*S1AMLA
   16 CONTINUE
      IF(KDR.GT.0.0) GO TO 18
      IOUT=0
      CAKDR = 0.783
      CBKDR = 0.222
      TRBLP5 = S1BLP/(1.0-1.0/EXP(2.3*1.4*DTIM))
      S1BODT = S1BOD + TRBLP5 + S1AMB5
   17 KDR = CAKDR*(S1BODT**CBKDR)
      KKDR = 2.3*KDR
      IOUT=IOUT+1
      IF(IOUT.GE.3) GO TO 19
      S1BLP5=S1BLP/(1.0-1.0/EXP(KKDR*DTIM))
      S1BODT=S1BOD+S1BLP5+S1AMB5
      GO TO 17
   18 KKDR = 2.3*KDR
      S1BLP5=S1BLP/(1.0-1.0/EXP(KKDR*DTIM))
      S1BODT=S1BOD+S1BLP5+S1AMB5
      CBKDR = 0.2
      CAKDR = KDR/(S1BODT**CBKDR)
   19 CONTINUE
      IF(LAE.GT.0.0) GO TO 20
      LAE = BODE/(1.0-(1.0/EXP(KKDE*5.0)))
   20 IF(LAR.GT.0.0) GO TO 21
      LAR = BODR/(1.0-(1.0/EXP(KKDRLB*5.0)))
   21 CONTINUE
      LADQ = BODDQ/(1.0-(1.0/EXP(KKDRLB*5.0)))
      S1LABL=S1BLP5/(1.0-(1.0/EXP(KKDRLB*5.0)))
      STGLA=GAMMA1*LAR
      STGBLT=GAMMA1*S1LABL
      STGCB=STGLA+STGBLT
      STGNB=GAMMA2*BODAMR
      STGTB=STGCB+STGNB
```

```
      BLXLA = BLX/(1.0-(1.0/EXP(KKDRLB*5.0)))
      DBLXLA = DBLX/(1.0-(1.0/EXP(KKDRLB*5.0)))
C     **
C     ** COMPUTE WATER TEMPERATURE FROM AIR TEMP DATA IF NEEDED
C     **
      IF(TPBRD.GT.0.0) GO TO 23
      DIFTMP = 1.25*QRCFS**0.30
      TPBRD = TMPAD - DIFTMP
      TPBRN = TMPAN + DIFTMP
   23 TMPR = (TPBRD+TPBRN)/2.0
      TMPC = (5.0/9.0)*(TMPR-32.0)
C     **
C     **  COMPUTE ALGAE AND COLIFORM CONTROL PARAMETERS
C     **
      IF(ABS(TMPC-20.0).LE.0.10) GO TO 302
      IF(TMPC-20.0) 301,302,303
  301 SIGTP = 1.0/(1.01**(20.0-TMPC))
      COLTPF = 2.0/(1.05**(20.0-TMPC))
      TAUTX = TAUTM*(1.07**(20.0-TMPC))
      GO TO 304
  302 SIGTP = 1.00
      COLTPF = 2.0
      TAUTX = TAUTM
      GO TO 304
  303 SIGTP = 1.01**(TMPC-20.0)
      COLTPF = 2.0*(1.05**(TMPC-20.0))
      TAUTX = TAUTM/(1.07**(TMPC-20.0))
  304 CONTINUE
      PO4RM = (PO4E*QECFS+PO4R*QRCFS)/(QRXIN)
      IF(PO4RM.GE.1.0) GO TO 704
      SIGAL = CAALG*(PO4RM**(CBALG*5.0))
      GO TO 705
  704 SIGAL = CAALG*PO4RM**CBALG
  705 CONTINUE
      SIGMA = (SIGTP*SIGAL)-1.0
      IF(IWTRA.EQ.0) GO TO 308
      GO TO (305,306,307), IWTRA
```

```
  305 SIGMA=0.5*SIGMA
      GO TO 308
  306 SIGMA = 0.20*SIGMA
      GO TO 308
  307 SIGMA = 0.10*SIGMA
  308 IF(SIGMA) 309,310,310
  309 SIGMA=0.0
  310 TCHEK = 2.0*TAUTX
C     **
C     **  PRIMARY DO LOOP FOR DAY AND NIGHT COMPUTATIONS
C     **  COMPUTE VALUES OF WATER QUALITY PARAMETERS AFTER
C     **       MIXING AT EFFLUENT DISCHARGE POINT
C     **             **  STATION 1 DATA  **
C     **
      DO 60 ID=1,2
      IF(IWRIT.EQ.0) GO TO 395
      WRITE(3,980)
  395 CONTINUE
      IF(ID.EQ.2) GO TO 24
      TEMPR=TMPRD
      TMPBR=TPBRD
      PCSR=PCSRD
      PCSDQ=PSDQD
      GO TO 25
   24 TEMPR=TMPRN
      TMPBR=TPBRN
      PCSR=PCSRN
      PCSDQ=PSDQN
   25 QRX(ID,1)=QRXIN
      TIMX(ID,1)=TIMIN
      XMI(ID,1)=XIN
      UX = CVA*QRXIN**CVB
      DELX = UX*24.0*DTIM
      DELQT = DELX*DELQX
      TEMPRX(ID,1)= (TEMPE*QECFS+TEMPR*QRCFS)/QRXIN
      DIFT1 = TMPBR-TEMPRX(ID,1)
      TMPC = (5.0/9.0)*(TEMPRX(ID,1)-32.0)
```

```
      DOSRT = DOS(TMPC)
      TEC1=(5.0/9.0)*(TEMPE-32.0)
      DOEI = PCSE*DOS(TEC1)/100.0
      TRC1=(5.0/9.0)*(TEMPR-32.0)
      DORI = PCSR*DOS(TRC1)/100.0
      DORX(ID,1) =(DORI*QRCFS+DOEI*QECFS)/QRXIN
      DODEF(ID,1) = DOSRT - DORX(ID,1)
      TSAV(ID)= TIMX(ID,1)
      XSAV(ID)= XMI(ID,1)
      DOMN(ID) = DORX(ID,1)
      DORG(ID) = DORI
C     **
C     **  COMPUTE COEFFICIENTS FOR RIVER WATER TEMPERATURE
C     **          AT STATION 1
C     **
      IF(K2R.GT.0.0) GO TO 27
      QX = QRX(ID,1)
      K2ER = AKRQ(QX)
      GO TO 28  -
   27 K2ER = 2.3*K2R
   28 CONTINUE
      IF(ABS(TMPC-20.0).LE.0.10) GO TO 312
      IF(TMPC-20.0) 311,312,313
  311 KKDRX = KKDR/(1.047**(20.0-TMPC))
      KKCOLX= KKCOL/(1.05**(20.0-TMPC))
      KKNRX = KKNR/(1.080**(20.0-TMPC))
      KKNTX = KKNTR/(1.08**(20.0-TMPC))
      KKPOX = KKPOR/(1.08**(20.0-TMPC))
      K2RX(ID,1) = K2ER/(1.0241**(20.0-TMPC))
      GO TO 315
  312 KKDRX = KKDR
      KKCOLX= KKCOL
      KKNRX = KKNR
      KKNTX = KKNTR
      KKPOX = KKPOR
      K2RX(ID,1) = K2ER
      GO TO 315
```

```
  313 KKDRX = KKDR*(1.047**(TMPC-20.0))
      KKCOLX= KKCOL*(1.05**(TMPC-20.0))
      KKNRX = KKNR*(1.080**(TMPC-20.0))
      KKNTX = KKNTR*(1.08**(TMPC-20.0))
      KKPOX = KKPOR*(1.08**(TMPC-20.0))
      K2RX(ID,1) = K2ER*(1.0241**(TMPC-20.0))
  315 CONTINUE
      IF(DORX(ID,1).LT.0.5) GO TO 317
      KDFCT(ID,1) = 1.0-(KKDRX*DTIM)
      KNFCT(ID,1) = 1.0-(KKNRX*DTIM)
      KNTFCT(ID,1)= 1.0-(KKNTX*DTIM)
      COLFCT(ID,1) = 1.0-(KKCOLX*DTIM)
      KPFCT(ID,1) = 1.0-(KKPOX*DTIM)
      ALFCT(ID,1) = KKDRX*ALPHA
      BEFCT(ID,1) = KKNRX
      IF(DORX(ID,1).GE.2.0) GO TO 318
      DONFCT=(1.0-BETA)+((BETA/1.5)*(DORX(ID,1)-0.5))
      KNFCT(ID,1) = 1.0-(DONFCT*KKNRX*DTIM)
      BEFCT(ID,1) = KKNRX*DONFCT
      GO TO 318
  317 DORFCT = 0.75+ 0.50*DORX(ID,1)
      KDFCT(ID,1) = 1.0-(KKDRX*DTIM*DORFCT)
      DONFCT = 1.0 - BETA
      KNFCT(ID,1) = 1.0-(DONFCT*KKNRX*DTIM)
      KNTFCT(ID,1)= 1.0-(KKNTX*DTIM*DORFCT)
      COLFCT(ID,1) = 1.0-(KKCOLX*DTIM*DORFCT)
      KPFCT(ID,1) = 1.0-(KKPOX*DTIM*DORFCT)
      ALFCT(ID,1) = KKDRX*ALPHA*DORFCT
      BEFCT(ID,1) = KKNRX*DONFCT
  318 CONTINUE
C     **
C     **  INITIAL ALGAE RELATIONSHIPS AND ICE COVER REAERATION
C     **
      PRR = PRRIN
      IF(TEMPRX(ID,1).GT.32.5) GO TO 29
      K2RX(ID,1) = 2.3*K2ICE
   29 IF(IWTRA.EQ.0) GO TO 30
```

```
      GO TO (330,332,333), IWTRA
  330 IF(ID.EQ.2) GO TO 331
      ALGRX(ID,1) = PMR/2.0
      GO TO 32
  331 RESP = (PMR/2.0)/(PRR-1.0)
      ALGRX(ID,1) = -RESP
      GO TO 32
  332 IF(ID.EQ.2) GO TO 333
      ALGRX(ID,1) = PMR/5.0
      GO TO 32
  333 RESP = (PMR/5.0)/(PRR-1.0)
      ALGRX(ID,1) = -RESP
      GO TO 32
   30 IF(ID.EQ.2) GO TO 31
      ALGRX(ID,1) = PMR
      GO TO 32
   31 RESP = PMR/(PRR-1.0)
      ALGRX(ID,1) = -RESP
   32 CONTINUE
C     **
C     **  COMPUTE OTHER WATER QUALITY PARAMETERS
C     **
      LAERM(ID,1) = GAMMA1*(LAE*QECFS+LAR*QRCFS)/QRXIN
      BLP(ID,1) = GAMMA1*(4.45*BLXLA*DTIM*UX)/QRXIN
      LABL(ID,1) = BLP(ID,1)/(1.0 - 1.0/EXP(KKDR*DTIM))
      LAAMN(ID,1)= GAMMA2*(BODAME*QECFS+BODAMR*QRCFS)/QRXIN
      AMNRM(ID,1)= (AMNE*QECFS+AMNR*QRCFS)/QRXIN
      LACBN(ID,1) = LAERM(ID,1)+LABL(ID,1)
      LATX(ID,1) = LACBN(ID,1)+LAAMN(ID,1)
      COLIX(ID,1) = (COLIE*QECFS+COLIR*QRCFS)/QRXIN
      COLIDF = COLIX(ID,1)*(COLTPF-1.0)
      NITRX(ID,1) = (NITRE*QECFS+NITRR*QRCFS)/QRXIN
      PO4RX(ID,1) = PO4RM
C     **
C     **  SECONDARY DO LOOP FOR SPATIAL VARIATIONS IN WATER QUALITY
C     **  CONTINUE DOWNSTREAM AND COMPUTE WATER QUALITY LEVELS
C     **       FOR SELECTED PARAMETERS
```

```
C     **           ALLOW :OXIDATION OF NONCONSERVATIVE MATERIAL
C     **                  MIXING WITH ADDITIONAL INFLOW
C     **                  BOD ADDITIONS FROM BOUNDARY
C     **                  TRANSLATION AND MIXING OF
C     **                      CONSERVATIVE MATERIALS, ETC.
C     **
C     **
C     **  COMPUTE FLOW PARAMETERS AT END OF SPATIAL INCREMENT
C     **
      DO 60 J=2,NT
      QRX(ID,J) = QRX(ID,J-1) + DELQT
      XMI(ID,J) = XMI(ID,J-1) + DELX
      QRATIO = QRX(ID,J-1)/QRX(ID,J)
      TIMX(ID,J) = TIMX(ID,J-1) + DTIM
      TEMPRX(ID,J) = TMPBR - DIFT1/EXP(KETBR*TIMX(ID,J))
      TMPC =(5.0/9.0)*(TEMPRX(ID,J)-32.0)
C     **
C     **  COMPUTE RIVER EFFECT ON EFFLUENT LOAD AND
C     **       DISSOLVED OXYGEN LEVELS ** 5 TERMS
C     **
C     **
C     **  COMPUTE REAERATION EFFECT ON DISSOLVED OXYGEN AND TERM 1
C     **                              AND
C     **  COMPUTE RIVER EFFECT ON EFFLUENT LOAD AND TERM 2
C     **
      TERM1=-(K2RX(ID,J-1)*DODEF(ID,J-1)*DTIM)
      TERM2 = ALFCT(ID,J-1)*LAERM(ID,J-1)*DTIM/GAMMA1
      LAERMU = LAERM(ID,J-1)*KDFCT(ID,J-1)
      LAERM(ID,J) = LAERMU*QRATIO
C     **
C     **  COMPUTE RIVER EFFECT ON BOUNDARY BOD ADDITIONS
C     **       AND TERM 3
C     **
      TERM3 = ALFCT(ID,J-1)*LABL(ID,J-1)*DTIM/GAMMA1
      XDIST = XMI(ID,J) - XMI(ID,1)
      BLT = BLXLA + (DBLXLA*XDIST)
      BLP(ID,J) = GAMMA1*(4.45*BLT*DTIM*UX)/QRX(ID,J)
```

```
      LABLU=BLP(ID,J-1) + KDFCT(ID,J-1)*LABL(ID,J-1)
      LABL(ID,J) = (LABLU*QRX(ID,J-1)+GAMMA1*LADQ*DELQT)/QRX(ID,J)
C     **
C     **  COMPUTE RIVER EFFECT ON NITROGEN LEVELS AND TERM 4
C     **
      TERM4 = BEFCT(ID,J-1)*LAAMN(ID,J-1)*DTIM/GAMMA2
      AMNRMU = AMNRM(ID,J-1)*KNFCT(ID,J-1)
      AMNRM(ID,J) =(AMNRMU*QRX(ID,J-1)+AMNR*DELQT)/QRX(ID,J)
      LAAMNU = LAAMN(ID,J-1)*KNFCT(ID,J-1)
      LAAMN(ID,J)=(LAAMNU*QRX(ID,J-1)+GAMMA2*BODAMR*DELQT)/QRX(ID,J)
      IF(DORX(ID,J-1).GT.2.0) GO TO 42
      IF(DORX(ID,J-1).GT.0.5) GO TO 41
      AMNCON = 0.0
      GO TO 43
   41 AMNCON = (BETA/1.5)*((DORX(ID,J-1)-0.5)*(AMNRM(ID,J-1)-AMNRMU))
      GO TO 43
   42 AMNCON = BETA*(AMNRM(ID,J-1)-AMNRMU)
   43 CONTINUE
C     **
C     **  COMPUTE EFFECT OF ALGAE AND TERM 5
C     **        P AND R IN DAYTIME, R ONLY AT NIGHT
C     **
      TERM5 =-ALGRX(ID,J-1)*DTIM*24.0
      IF(TIMX(ID,J).GT.TCHEK) GO TO 47
      ANGLE = 3.1416*TIMX(ID,J)/TAUTX
      ALGA = 1.0 - COS(ANGLE)
      ALGT = 1.0 + (0.5*SIGMA*ALGA)
      PRR = PRRIN + (PRRMX-PRRIN)*0.5*ALGA
      GO TO 48
   47 ALGT = 1.0
      PRR = PRRIN
   48 IF(IWTRA.EQ.0) GO TO 50
      GO TO (630,632,633), IWTRA
  630 IF(ID.EQ.2) GO TO 631
      ALGRX(ID,J) = (PMR/2.0)*ALGT
      GO TO 52
  631 RESP = (PMR/2.0)/(PRR-1.0)
```

```
      ALGRX(ID,J) = -RESP*ALGT
      GO TO 52
  632 IF(ID.EQ.2) GO TO 633
      ALGRX(ID,J) = (PMR/5.0)*ALGT
      GO TO 52
  633 RESP = (PMR/5.0)/(PRR-1.0)
      ALGRX(ID,J) = -RESP*ALGT
      GO TO 52
   50 IF(ID.EQ.2) GO TO 51
      ALGRX(ID,J) = PMR*ALGT
      GO TO 52
   51 RESP = PMR/(PRR-1.0)
      ALGRX(ID,J) = -RESP*ALGT
   52 CONTINUE
C     **
C     **  COMPUTE CHANGE IN DISSOLVED OXYGEN LEVELS, TERMS 1 TO 5
C     **
      DOSRT = DOS(TMPC)
      TPDQ=(5.0/9.0)*(TMPBR-32.0)
      DODQ = DOS(TPDQ)*PCSDQ/100.0
      DELDEF(ID,J) = TERM1+TERM2+TERM3+TERM4+TERM5
      DORXU = DORX(ID,J-1) - DELDEF(ID,J)
      DORX(ID,J) = (DORXU*QRX(ID,J-1)+DODQ*DELQT)/QRX(ID,J)
      DODEF(ID,J) = DOSRT - DORX(ID,J)
      IF(DORX(ID,J).GT.0.0) GO TO 55
      DORX(ID,J) = 0.0
      DODEF(ID,J) = DOSRT
   55 IF(DORX(ID,J).GE.DOMN(ID)) GO TO 56
      DOMN(ID) = DORX(ID,J)
      XSAV(ID) = XMI(ID,J)
      TSAV(ID) = TIMX(ID,J)
   56 CONTINUE
C     **
C     **  ADD TOTAL LEVELS OF REMAINING OXYGEN DEMAND AND
C     **  COMPUTE LEVELS OF MISCELLANEOUS WATER QUALITY PARAMETERS
C     **
      LACBN(ID,J) = LAERM(ID,J) + LABL(ID,J)
```

```
      LATX(ID,J) = LACBN(ID,J) + LAAMN(ID,J)
      PO4RXU = PO4RX(ID,J-1)*KPFCT(ID,J-1)
      PO4RX(ID,J) =(PO4RXU*QRX(ID,J-1)+PO4R*DELQT)/QRX(ID,J)
      NITRXU =(NITRX(ID,J-1)*KNTFCT(ID,J-1)) + AMNCON
      NITRX(ID,J) =(NITRXU*QRX(ID,J-1)+NITRR*DELQT)/QRX(ID,J)
      IF(AMNRM(ID,J).GT.AMNR) GO TO 740
      AMNRM(ID,J) = AMNR
  740 IF(NITRX(ID,J).GT.NITRR) GO TO 741
      NITRX(ID,J) = NITRR
  741 IF(PO4RX(ID,J).GT.PO4R) GO TO 742
      PO4RX(ID,J) = PO4R
  742 CONTINUE
      IF(BODE.GT.150.0) GO TO 756
      COLIU = COLIX(ID,J-1)*COLFCT(ID,J-1)
      COLIX(ID,J) =(COLIU*QRX(ID,J-1)+COLIR*DELQT)/QRX(ID,J)
      GO TO 58
  756 CONTINUE
      IF(TIMX(ID,J-1).LT.0.5) GO TO 57
      COLIU = COLIX(ID,J-1)*COLFCT(ID,J-1)
      COLIX(ID,J) =(COLIU*QRX(ID,J-1)+COLIR*DELQT)/QRX(ID,J)
      GO TO 58
   57 COLIU = COLIX(ID,J-1)+(COLIDF*TIMX(ID,J)/0.5)
      COLIX(ID,J) =(COLIU*QRX(ID,J-1)+COLIR*DELQT)/QRX(ID,J)
   58 CONTINUE
      IF(COLIX(ID,J).GT.COLIR) GO TO 743
      COLIX(ID,J) = COLIR
  743 CONTINUE
C     **
C     **  COMPUTE NEW RATE COEFFICIENTS
C     **
      UX = CVA*QRX(ID,J)**CVB
      DELX = UX*24.0*DTIM
      DELQT = DELX*DELQX
      IF(GAMMA1.GE.1.0) GO TO 342
      KKDR = 2.3*CAKDR*(LATX(ID,J)**CBKDR)
      GO TO 343
  342 SXBOD = 0.80*LACBN(ID,J)+0.60*LAAMN(ID,J)
```

```
      KKDR = 2.3*CAKDR*(SXBOD**CBKDR)
  343 CONTINUE
      IF(K2R.GT.0.0) GO TO 344
      QX = QRX(ID,J)
      K2ER = AKRQ(QX)
      GO TO 345
  344 K2ER = 2.3*K2R
  345 CONTINUE
      IF(ABS(TMPC-20.0).LE.0.10) GO TO 322
      IF(TMPC-20.0) 321,322,323
  321 KKDRX = KKDR/(1.047**(20.0-TMPC))
      KKCOLX= KKCOL/(1.05**(20.0-TMPC))
      KKNRX = KKNR/(1.080**(20.0-TMPC))
      KKNTX = KKNTR/(1.08**(20.0-TMPC))
      KKPOX = KKPOR/(1.08**(20.0-TMPC))
      K2RX(ID,J) = K2ER/(1.0241**(20.0-TMPC))
      GO TO 325
  322 KKDRX = KKDR
      KKCOLX= KKCOL
      KKNRX = KKNR
      KKNTX = KKNTR
      KKPOX = KKPOR
      K2RX(ID,J) = K2ER
      GO TO 325
  323 KKDRX = KKDR*(1.047**(TMPC-20.0))
      KKCOLX= KKCOL*(1.05**(TMPC-20.0))
      KKNRX = KKNR*(1.080**(TMPC-20.0))
      KKNTX = KKNTR*(1.08**(TMPC-20.0))
      KKPOX = KKPOR*(1.08**(TMPC-20.0))
      K2RX(ID,J) = K2ER*(1.0241**(TMPC-20.0))
  325 CONTINUE
      IF(TEMPRX(ID,J).GT.32.5) GO TO 346
      K2RX(ID,J) = 2.3*K2ICE
  346 CONTINUE
      IF(DORX(ID,J).LT.0.5) GO TO 327
      KDFCT(ID,J) = 1.0-(KKDRX*DTIM)
      KNFCT(ID,J) = 1.0-(KKNRX*DTIM)
```

```
      KNTFCT(ID,J)= 1.0-(KKNTX*DTIM)
      COLFCT(ID,J) = 1.0-(KKCOLX*DTIM)
      KPFCT(ID,J) = 1.0-(KKPOX*DTIM)
      ALFCT(ID,J) = KKDRX*ALPHA
      BEFCT(ID,J) = KKNRX
      IF(DORX(ID,J).GE.2.0) GO TO 328
      DONFCT=(1.0-BETA)+((BETA/1.5)*(DORX(ID,J)-0.5))
      KNFCT(ID,J) = 1.0-(DONFCT*KKNRX*DTIM)
      BEFCT(ID,J) = KKNRX*DONFCT
      GO TO 328
  327 DORFCT = 0.75+ 0.50*DORX(ID,J)
      KDFCT(ID,J) = 1.0-(KKDRX*DTIM*DORFCT)
      DONFCT = 1.0 - BETA
      KNFCT(ID,J) = 1.0-(DONFCT*KKNRX*DTIM)
      KNTFCT(ID,J)= 1.0-(KKNTX*DTIM*DORFCT)
      COLFCT(ID,J) = 1.0-(KKCOLX*DTIM*DORFCT)
      KPFCT(ID,J) = 1.0-(KKPOX*DTIM*DORFCT)
      ALFCT(ID,J) = KKDRX*ALPHA*DORFCT
      BEFCT(ID,J) = KKNRX*DONFCT
  328 CONTINUE
C     **
C     **  WRITE OUT THE FIVE TERMS AND OTHER DATA IF REQUESTED
C     **
C     **
      IF(IWRIT.EQ.0) GO TO 791
      WRITE(3,981)TIMX(ID,J),XMI(ID,J),TERM1,TERM2,TERM3,TERM4,
     1 TERM5,DODEF(ID,J),DORX(ID,J),DOSRT,K2RX(ID,J),KKDRX
  791 CONTINUE
   60 CONTINUE
C     **
C     **  AVERAGE DAY AND NIGHT VALUES FOR DAILY AVERAGES
C     **
      DO 65 J=1,NT
      DORX(3,J) =(DORX(1,J)+DORX(2,J))/2.0
      TIMX(3,J) =(TIMX(1,J)+TIMX(2,J))/2.0
      XMI(3,J) =(XMI(1,J)+XMI(2,J))/2.0
      QRX(3,J) =(QRX(1,J)+QRX(2,J))/2.0
```

```
      TEMPRX(3,J) =(TEMPRX(1,J)+TEMPRX(2,J))/2.0
      LAERM(3,J) =(LAERM(1,J)+LAERM(2,J))/2.0
      LABL(3,J) =(LABL(1,J)+LABL(2,J))/2.0
      LACBN(3,J) =(LACBN(1,J)+LACBN(2,J))/2.0
      LAAMN(3,J) =(LAAMN(1,J)+LAAMN(2,J))/2.0
      LATX(3,J) =(LATX(1,J)+LATX(2,J))/2.0
      AMNRM(3,J) =(AMNRM(1,J)+AMNRM(2,J))/2.0
      COLIX(3,J) =(COLIX(1,J)+COLIX(2,J))/2.0
      PO4RX(3,J) =(PO4RX(1,J)+PO4RX(2,J))/2.0
      NITRX(3,J) =(NITRX(1,J)+NITRX(2,J))/2.0
      DODEF(3,J) =(DODEF(1,J)+DODEF(2,J))/2.0
   65 CONTINUE
C     **
C     **   WRITE OUT RESULTS IN DESIGNATED TABLES
C     **        NUMBER OF LINES PER PAGE CONTROLLED
C     **               BY PARAMETER NLIN
C     **
      IF(NLIN.GE.10) GO TO 411
      NLIN=40
  411 NS=1
      IPC=1
      IF(NT.GT.NLIN) GO TO 412
      NE = NT
      GO TO 413
  412 NE = NLIN
  413 CONTINUE
      WRITE(3,250) IDENT1,IDENT2,ISESON
      WRITE(3,251)
      IF(IPC.GT.1) GO TO 414
      WRITE(3,255)TIMX(3,1),XGAGE,TMPRD,TMPRN,QRCFS,DORG(1),DORG(2),
     1 AMNR
      IPC=IPC+1
  414 CONTINUE
      DO 415 J=NS,NE
      WRITE(3,252)TIMX(3,J),XMI(3,J),TEMPRX(1,J),TEMPRX(2,J),
     1 TEMPRX(3,J),QRX(3,J),DORX(1,J),DORX(2,J),DORX(3,J),
     2 AMNRM(3,J)
```

```
415 CONTINUE
    IF(NE.GE.NT) GO TO 420
    NS = NE+1
    NE = NS+NLIN-1
    IF(NT.GT.NE) GO TO 413
    NE = NT
    GO TO 413
420 CONTINUE
    NS=1
    IPC=1
    IF(NT.GT.NLIN) GO TO 422
    NE = NT
    GO TO 423
422 NE = NLIN
423 CONTINUE
    WRITE(3,250) IDENT1,IDENT2,ISESON
    IF(GAMMA1.GE.1.0) GO TO 523
    WRITE(3,256)
    GO TO 524
523 WRITE(3,257)
524 CONTINUE
    WRITE(3,261)
    IF( IPC.GT.1) GO TO 424
    WRITE(3,262)TIMX(3,1),XGAGE,STGLA,STGBLT,STGCB,STGNB,STGTB,
   1 NITRR,PO4R,COLIR
    IPC=IPC+1
424 CONTINUE
    DO 425 J=NS,NE
    WRITE(3,262)TIMX(3,J),XMI(3,J),LAERM(3,J),LABL(3,J),LACBN(3,J),
   1 LAAMN(3,J),LATX(3,J),NITRX(3,J),PO4RX(3,J),COLIX(3,J)
425 CONTINUE
    IF(NE.GE.NT) GO TO 430
    NS=NE+1
    NE=NS+NLIN-1
    IF(NT.GT.NE) GO TO 423
    NE=NT
    GO TO 423
```

```
  430 CONTINUE
C      **
C      **  WRITE OUT INITIAL, FINAL VALUES FOR WATER QUALITY PARAMETERS
C      **        AT BEGINNING AND END OF ASSIMILATIVE REACH
C      **
       ICHEK =((2.0/DTIM)*TAUTM) + 0.1
       ICHEK=ICHEK+1
       IF(ICHEK.LE.NT) GO TO 432
       ICHEK = NT
  432  NSAV = NT
       NT = ICHEK
       WRITE(3,240)IDENT1,IDENT2,ISESON
       IF(GAMMA1.GE.1.0) GO TO 435
       WRITE(3,256)
       GO TO 436
  435  WRITE(3,257)
  436  CONTINUE
       WRITE(3,270)
       WRITE(3,271)DORX(1,1),XMI(1,1),TIMX(1,1),DORX(2,1),XMI(2,1),
     1 TIMX(2,1),DOMN(1),XSAV(1),TSAV(1),DOMN(2),XSAV(2),TSAV(2),
     2 DORX(1,NT),XMI(1,NT),TIMX(1,NT),DORX(2,NT),XMI(2,NT),TIMX(2,NT)
       WRITE(3,272)DODEF(1,1),XMI(1,1),TIMX(1,1),DODEF(2,1),XMI(2,1),
     1 TIMX(2,1),DODEF(1,NT),XMI(1,NT),TIMX(1,NT),DODEF(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
       WRITE(3,273)QRX(1,1),XMI(1,1),TIMX(1,1),QRX (2,1),XMI(2,1),
     1 TIMX(2,1),QRX(1,NT),XMI(1,NT),TIMX(1,NT),QRX(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
       WRITE(3,274)TEMPRX(1,1),XMI(1,1),TIMX(1,1),TEMPRX(2,1),
     1 XMI(2,1),TIMX(2,1),TEMPRX(1,NT),XMI(1,NT),TIMX(1,NT),
     2 TEMPRX(2,NT),XMI(2,NT),TIMX(2,NT)
       WRITE(3,275)LAERM(1,1),XMI(1,1),TIMX(1,1),LAERM(2,1),XMI(2,1),
     1 TIMX(2,1),LAERM(1,NT),XMI(1,NT),TIMX(1,NT),LAERM(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
       WRITE(3,276)BLP(1,1),XMI(1,1),TIMX(1,1),BLP(2,1),XMI(2,1),
     1 TIMX(2,1),LABL(1,NT),XMI(1,NT),TIMX(1,NT),LABL(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
       WRITE(3,277)LAAMN(1,1),XMI(1,1),TIMX(1,1),LAAMN(2,1),XMI(2,1),
```

```
     1 TIMX(2,1),LAAMN(1,NT),XMI(1,NT),TIMX(1,NT),LAAMN(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
      WRITE(3,278)LATX(1,1),XMI(1,1),TIMX(1,1),LATX(2,1),XMI(2,1),
     1 TIMX(2,1),LATX(1,NT),XMI(1,NT),TIMX(1,NT),LATX(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
      WRITE(3,279)AMNRM(1,1),XMI(1,1),TIMX(1,1),AMNRM(2,1),XMI(2,1),
     1 TIMX(2,1),AMNRM(1,NT),XMI(1,NT),TIMX(1,NT),AMNRM(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
      WRITE(3,280)NITRX(1,1),XMI(1,1),TIMX(1,1),NITRX(2,1),XMI(2,1),
     1 TIMX(2,1),NITRX(1,NT),XMI(1,NT),TIMX(1,NT),NITRX(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
      WRITE(3,281)PO4RX(1,1),XMI(1,1),TIMX(1,1),PO4RX(2,1),XMI(2,1),
     1 TIMX(2,1),PO4RX(1,NT),XMI(1,NT),TIMX(1,NT),PO4RX(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
      WRITE(3,282)COLIX(1,1),XMI(1,1),TIMX(1,1),COLIX(2,1),XMI(2,1),
     1 TIMX(2,1),COLIX(1,NT),XMI(1,NT),TIMX(1,NT),COLIX(2,NT),
     2 XMI(2,NT),TIMX(2,NT)
      NT = NSAV
C     **
C     **  WRITE OUT COEFFICIENT MATRIX ONLY IF REQUESTED
C     **
      IF(IWRIT.EQ.0) GO TO 491
      DO 490 ID=1,2
      WRITE(3,250) IDENT1,IDENT2,ISESON
      WRITE(3,289)ID
      WRITE(3,290)
      DO 490 J=1,NT
      WRITE(3,291)TIMX(ID,J),XMI(ID,J),KDFCT(ID,J),KNFCT(ID,J),
     1 KNTFCT(ID,J),KPFCT(ID,J),K2RX(ID,J),COLFCT(ID,J),ALFCT(ID,J),
     2 BEFCT(ID,J),ALGRX(ID,J),DODEF(ID,J)
  490 CONTINUE
  491 CONTINUE
C     **
C     **  PLOTTING ROUTINE FOR DISSOLVED OXYGEN AND BOD RESULTS
C     **       USING DAY, AVG, AND NIGHT DO AND AVG BOD RESULTS
C     **
      IF(IPLOT.EQ.0) GO TO 890
```

```
      READ(1,901)XLAB,YLAB,GLAB,DATLAB
      READ(1,902)DL3,DL2
      READ(1,903)WLAB,ZLAB,BLAB,DAZLAB
      READ(1,904)DL4,DL5
      READ(1,905)XSF,YSF,ZSF
C     **
C     ** TRANSFER RESULTS TO PLOTTING ARRAYS
C     **
      DO 810 J=1,NT
      XMI1(J)=XMI(1,J)
      DOR1(J)=DORX(1,J)
      XMI2(J)=XMI(2,J)
      DOR2(J)=DORX(2,J)
      XMI3(J)=XMI(3,J)
      DOR3(J)=DORX(3,J)
      YBOD(J)=LAERM(3,J)
      AAMN(J)=AMNRM(3,J)
      ZBOD(J)=LATX(3,J)
  810 CONTINUE
C     **
C     **  PLOT DO RESULTS
C     **
      CALL GRAPH (NT,XMI1,DOR1,1,107,7.5,5.0,XSF,0.0,YSF,0.0,
     1 XLAB,YLAB,GLAB,DATLAB)
      CALL GRAPH (NT,XMI3,DOR3,3,107,0,0,0,0,0,0,0,0,0,DL3)
      CALL GRAPH (NT,XMI2,DOR2,2,107,0,0,0,0,0,0,0,0,0,DL2)
C     **
C     **  PLOT BOD RESULTS
C     **
      CALL GRAPH (NT,XMI3,ZBOD,5,107,7.5,5.0,XSF,0.0,ZSF,0.0,
     1 WLAB,ZLAB,BLAB,DAZLAB)
      CALL GRAPH (NT,XMI3,YBOD,6,107,0,0,0,0,0,0,0,0,0,DL4)
      CALL GRAPH (NT,XMI3,AAMN,3,107,0,0,0,0,0,0,0,0,0,DL5)
  890 CONTINUE
C     **
C     **  PUNCH OUT RESULTS ON 80 COLUMN DATA CARDS
C     **       IF REQUESTED, FOR SAME WATER QUALITY PARAMETERS
```

```
C     **       AS PRINTED OUT IN TABLES
C     **
      IF(IPNCH.EQ.0) GO TO 595
      IF(IPNCH.GE.2) GO TO 595
      WRITE(2,551)IDENT1
      WRITE(2,552)IDENT2,ISESON
      WRITE(2,553)TIMX(3,J),XMI(3,J),TEMPRX(1,J),TEMPRX(2,J),
     1 TEMPRX(3,J),QRX(3,J),DORX(1,J),DORX(2,J),DORX(3,J),
     2 AMNRM(3,J)
      WRITE(2,554)TIMX(3,J),XMI(3,J),LAERM(3,J),LABL(3,J),LACBN(3,J),
     1 LAAMN(3,J),LATX(3,J),NITRX(3,J),PO4RX(3,J),COLIX(3,J)
  595 CONTINUE
C     **
C     **  CYCLE BACK TO STATION 1 AND RECOMPUTE RIVER REACTION
C     **      FOR THE PARAMETER SELECTED FOR ITERATION
C     **
C     **
C     * CYCLE FOR ADDITIONAL BANK LOAD ANALYSIS
C     **
      IF(DBLCY.LE.0.0) GO TO 86
      IF(IBLCY.EQ.0) GO TO 86
      IF(ICOUNT.GT.IBLCY) GO TO 85
      BLX = BLX + DBLCY
      ICHECK=ICHECK+1
      ICOUNT = ICOUNT + 1
      GO TO 4
   85 BLX = RWQD(12)
      ICHECK=1
      ICOUNT=0
   86 CONTINUE
C     **
C     **  CYCLE FOR LOW FLOW AUGMENTATION AND RESERVOIR STORAGE
C     **       ANALYSIS
C     **
      IF(DLQCY.LE.0.0) GO TO 88
      IF(IDQCY.EQ.0) GO TO 88
      IF(ICOUNT.GT.IDQCY) GO TO 87
```

```
      QRCFS = QRCFS+DLQCY
      ICHECK=ICHECK+1
      ICOUNT=ICOUNT+1
      IF(DOMN(2).GT.DOFSH) GO TO 87
      GO TO 4
   87 QRCFS = RQVD(1)
      ICHECK=1
      ICOUNT=0
   88 CONTINUE
C     **
C     **  CYCLE FOR ALGAE ANALYSIS
C     **
      IF(ILGCY.EQ.0) GO TO 405
      IF(ICOUNT.GT.ILGCY) GO TO 404
      PMR = PMR + DPMR
      ICHECK=ICHECK+1
      ICOUNT=ICOUNT+1
      GO TO 4
  404 PMR = ALGTP(9)
      ICHECK=1
      ICOUNT=0
  405 CONTINUE
C     **
C     **  MISCELLANEOUS RETURN AND STOP CONTROL
C     **
      GO TO 1
   89 WRITE(3,202)
      GO TO 1
   90 IF(KTYPE.EQ.0) GO TO 95
      WRITE(3,201)KTYPE
      GO TO 1
   95 WRITE(3,203)KTYPE
      STOP
C     **
C     **  INPUT FORMAT
C     **
  101 FORMAT(I2,8X,15A4)
```

```
  102 FORMAT(I2,8X,15A4,2X,2A4)
  103 FORMAT(I2,3X,15F5.0)
  104 FORMAT(I2,3X,I2,3X,F5.0,I2,3X,F5.0,I2,3X,F5.0,I2,3X,4(I2,8X))
  901 FORMAT(4(5A4))
  902 FORMAT(40X,2(5A4))
  903 FORMAT(4(5A4))
  904 FORMAT(40X,2(5A4))
  905 FORMAT(10X,3F10.2)
C     **
C     **  OUTPUT FORMAT
C     **
  200 FORMAT('1 '/////15X,'COMPUTER OUTPUT FOR STREAM WATER ',
     1 'QUALITY STUDIES')
  201 FORMAT('1 '/// 15X,'CARDS IN WRONG ORDER, KTYPE= ', I2)
  202 FORMAT('1 '/// 15X,'DTIM OR QRXIN = 0.0, CANNOT PROCEED')
  203 FORMAT('1 '/// 15X,'KTYPE=0, END OF RUN')
  206 FORMAT('1 '///T15,'GAMMA1 OR GAMMA2 =',F6.3,' CANNOT PROCEED')
  210 FORMAT('1 '/// 25X,'  AMES WATER QUALITY MODEL'/ 10X,
     1 'SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY'//
     2 15X,'INPUT DATA FOR THIS ANALYSIS' // 15X,'STREAM : ',
     3 15A4 / 15X,'RUN IDENT : ',15A4 /15X,'SEASON : ',2A4)
  211 FORMAT('0 ',15X, 'EFFLUENT DATA' // 10X,
     1'QEMGD TEMPE  PCSE',8X,'BODE   KDE   LAE   AMNE NITRE  PO4E',
     2 ' COLIE',13X,'GAMA1 GAMA2'/ 10X,5F6.2,F6.3,9F6.2)
  212 FORMAT('0 ',15X, 'RIVER WATER QUALITY DATA'// 10X,
     1'TMPRD TMPRN  PCSRD PCSRN BODR  KDRLB  LAR  AMNR   NITRR  PO4R',
     2' COLIR  BLX  DBLX ALPHA  BETA '/10X,5F6.2,F6.3,9F6.2)
  213 FORMAT('0 ',15X, 'RIVER DISCHARGE-VELOCITY DATA'// 10X,
     1'QRCFS DELQX PSDQD PSDQN  CVA   CVB   XIN   TIMIN TIMFN  DTIM',
     2 ' KCOLI KPOR  KNTR   KNR   KDR '/10X,4F6.2,2F6.3,4F6.2,5F6.3)
  214 FORMAT('0 ',15X, 'ALGAE AND AIR TEMPERATURE FACTORS'//10X,
     1'TPBRD TPBRN KCTBR TMPAD TMPAN CAALG  CBALG TAUTM  PMR  PRRIN',
     2 ' PRRMX BODDQ DOFSH K2ICE  K2R'/10X,2F6.2,F6.3,2F6.2,2F6.3,
     3 6F6.2,2F6.3)
  215 FORMAT('0 ',15X, 'MISCELLANEOUS CONTROL DATA'/ 10X,
     1 'IBLCY  DBLCY  IDQCY  DLQCY  ILGCY   DPMR IWTRA IPNCH',
     2 '        IWRIT       IPLOT      NLIN' / 8X,
```

```
     3 3(3X,I2,F9.2),2(3X,I2),3(9X,I2))
 230 FORMAT('0 ', T12, 'GAMMA1 = ',F6.2,' , GAMMA2 = ',F6.2/
    1 T11,'ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND ',
    2 'GAMMA2 = 1.0,'/T15,'OTHERWISE ANALYSIS IS FOR SIMULATED ',
    3 '5-DAY VALUES')
 231 FORMAT('0 '// T11,'IF PROGRAM IS CYCLING, THIS RUN IS FOR:'/
    1 T15,'CYCLE NO.',I3/ T15,'BANK LOAD IS ',F8.2,' LBS/DAY/MILE'
    2 ' AT FIRST STA., CYCLE FOR ',F5.1,' LBS/DAY/MILE '/
    3 T20,'ADDITIONAL BANK LOAD DOWNSTREAM IS ',F6.2,' LBS/DAY/MILE'/
    4 T15,'FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: ',F5.2,
    5 ' MG/L'/ T20,'EFFLUENT Q = ',F6.2,' CFS, RIVER Q = ',F6.2,
    6 ' CFS, TOTAL Q = ',F6.2,' CFS'/ T20,'CYCLE INCREMENT IS',F6.2,
    7 ' CFS'/ T15,'FOR ALGAE VARIATIONS, P-MINUS-R = ',F6.2,
    8' MG/L/HR'/  T20,'CYCLE INCREMENT IS',F6.2,' MG/L/HR')
 240 FORMAT('1 '////  T30,'WATER QUALITY IN SURFACE WATERS' /T34,
    1 'FOR SELECTED PARAMETERS' // T13,'STREAM :', 2X,15A4 /T13,
    2 'CONDITIONS :'/T16,15A4/T13,'SEASON :',2X, 2A4)
 250 FORMAT('1 '////  T12,'WATER QUALITY IN SURFACE WATERS ',
    1 'FOR SELECTED PARAMETERS' // T13,'STREAM :', 2X,15A4 /T13,
    2 'CONDITIONS :',2X,15A4/ T13, 'SEASON :', 2X,2A4)
 251 FORMAT('0 ',T13,'TIME  DISTANCE  RIVER TEMP-',10X,'RIVER',2X,
    1 'DISSOLVED OXYGEN LEVELS  AMMONIA '/ T14,'OF    DOWN-',6X,
    2'ERATURE',12X,'FLOW',4X,'DAY   NIGHT   AVG',7X,'LEVEL'/11X,
    3 'TRAVEL STREAM   DAY   NIGHT   AVG',5X,'CFS',5X,'MG/L   MG/L',
    4 4X,'MG/L',5X,'AVG' /T13,'DAYS   MILES  DEG F  DEG F  DEG F',
    5 36X,'MG/L'/)
 252 FORMAT('  ',8X,F6.2,F8.2,3F7.1,F8.1,1X,3F7.2,4X,F6.2)
 255 FORMAT('  ',8X,F6.2,F8.2,2F7.1,7X,F8.1,1X,2F7.2,11X,F6.2)
 256 FORMAT('  ',20X,'BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES')
 257 FORMAT('  ',20X,'BOD RESULTS ARE FOR ULTIMATE BOD VALUES')
 261 FORMAT('0 ',T13,'TIME  DISTANCE',7X,'AVERAGE LEVEL OF BOD ',
    1 'IN RIVER',5X,'NITRATE PHOSPHATE COLIFORM' / T14,'OF',
    2 4X,'DOWN-   EFFLUENT BOUND-  TOTAL   NITROG-  TOTAL   LEVEL',
    3 3X,'LEVEL    INDEX,'/T12, 'TRAVEL STREAM',5X,'BOD   ARY-BOD',
    4  ' CBN-BOD ENOUS-BOD  BOD', 4X,'NO3-N',4X,'PO4',5X,'PERCENT'/
    5 12X,'DAYS   MILES',5X,'MG/L',4X,'MG/L',4X,'MG/L',4X,'MG/L',
    6 4X,'MG/L',5X,'MG/L',4X,'MG/L',3X,'REMAINING'/)
```

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```
262 FORMAT('  ', 8X,F6.2,F8.2,2X,5F8.2,3F8.2)
270 FORMAT('0 ', T15, 'SUMMARY OF RESULTS FOR THE ASSIMILATIVE ',
   1 'REACH, 2*TAUTM DAYS'   //  T38, 'DAYTIME ',
   2 'VALUES',6X, 'NIGHTTIME VALUES'/ T35,'VALUE',3X,'MILE',3X,
   3 'DAY',3X,'VALUE   MILE   DAY'/ )
271 FORMAT('  ',T11, 'DISSOLVED OXYGEN'/T12,'INITIAL, MG/L', 8X,
   1 6F7.2/ T12,'MINIMUM DO, MG/L', 5X,6F7.2/T12,'FINAL DO, MG/L',
   2 7X,6F7.2)
272 FORMAT('  ', T11,'DO DEFICIT'/T12,'INITIAL, MG/L', 8X,6F7.2/
   1 T12,'FINAL, MG/L', 10X,6F7.2)
273 FORMAT('  ', T11,'RIVER DISCHARGE'/T12,'INITIAL, CFS', 9X,
   1 6F7.2/ T12,'FINAL, CFS',11X,6F7.2)
274 FORMAT('  ', T11,'RIVER TEMPERATURE'/T12,'INITIAL, DEG F',7X,
   1 6F7.2/ T12,'FINAL, DEG F', 9X,6F7.2)
275 FORMAT('  ', T11,'EFFLUENT BOD IN RIVER'/ T12,'INITIAL BOD',
   1 ',MG/L', 5X,6F7.2/ T12,'FINAL BOD, MG/L', 6X, 6F7.2)
276 FORMAT('  ',T11,'BOUNDARY BOD ADDITIONS'/  T12,'VALUE ',
   1 'PER MI-DAY,MG/L',    6F7.2 / T12,'FINAL BOD IN RIVER',
   2 3X,6F7.2)
277 FORMAT('  ', T11,'NITROGENOUS BOD'  / T12,'INITIAL BOD, MG/L',
   1 4X,6F7.2/ T12,'FINAL BOD, MG/L', 6X, 6F7.2)
278 FORMAT('  ', T11,'TOTAL CBN & NITR BOD LEVEL' / T12,'INITIAL',
   1 ' VALUE, MG/L',2X,6F7.2/T12,'FINAL VALUE, MG/L',4X,6F7.2)
279 FORMAT('  ', T11,'AMMONIA NITROGEN'/ T12,'INITIAL VALUE, MG/L',
   1 2X,6F7.2/ T12,'FINAL VALUE, MG/L',4X,6F7.2)
280 FORMAT('  ', T11,'NITRATE (NO2-NO3) NITROGEN'/T12,'INITIAL',
   1 ' VALUE, MG/L', 2X,6F7.2/ T12,'FINAL VALUE, MG/L',4X,6F7.2)
281 FORMAT('  ', T11,'PHOSPHATE PO4 LEVEL'/ T12,'INITIAL VALUE',
   1 ', MG/L',2X,6F7.2/ T12,'FINAL VALUE, MG/L',4X, 6F7.2)
282 FORMAT('  ', T11,'COLIFORM INDEX, % REMAINING'/ T12,
   1 'INITIAL PERCENT',6X,6F7.2/ T12,'FINAL PERCENT', 8X,5F7.2,
   2 F7.2)
289 FORMAT('0 ',T15,'ID=',I2,' **FOR DAY, ID=1, FOR NIGHT, ID=2**')
290 FORMAT('0 ', T8,'SPATIAL AND TEMPORAL VALUES OF COFFICIENTS',
   1' AND FACTORS'// T9,'TIME DIST KDFCT KNFCT KNTFT KPFCT K2RX',
   2' COLFCT ALFCT BEFCT ALGRX DODEF')
291 FORMAT('  ',3X,2F6.2,8F6.3,2F6.2)
```

```
551 FORMAT(10X,15A4)
552 FORMAT(10X,15A4,2X,2A4)
553 FORMAT(10F8.2)
554 FORMAT(10F8.2)
980 FORMAT('1 '///T20,'RUNNING PRINTOUT OF DISSOLVED OXYGEN TERMS'
   1 //T12,'TIME',3X,'MILE',3X,'TERM 1  TERM 2  TERM 3  TERM 4  ',
   2 'TERM 5  DISSOLVED OXYGEN'/ T26,'MG/L',4X,'MG/L',4X,'MG/L',
   3 4X,'MG/L',4X,'MG/L',3X,'DEFICIT  ACTUAL'/T66,'MG/L',
   4 5X,'MG/L',2X, 'DOSRT  K2RX(ID,J)  KKDRX'/)
981 FORMAT(10X,2F6.2,7F8.3,3F8.3)
    END
```

```
      FUNCTICN AKRQ(QY)
C     **
C     **  FUNCTION SUBPROGRAM   AKRQ(QY), FOR COMPUTING
C     **        REAERATION COEFFICIENT
C     **
      IF(QY.GE.100.0) GO TO 10
      AKRQ1=5.00/(QY**0.0185)
      GO TO 20
   10 AKRQ1=49.7/(QY**0.517)
   20 CONTINUE
      AKRQ= 2.3*AKRQ1
      RETURN
      END
      FUNCTION DOS(TMPX)
C     **
C     **  FUNCTION SUBPROGRAM DOS(TMPX) FOR COMPUTING
C     **        SATURATION DO VALUES
C     **
      TERMS1 = 0.41022*TMPX
      TERMS2 = 0.7991*((TMPX*TMPX)/100.0)
      TERMS3 = 0.77774*(((TMPX*TMPX)/100.0)*(TMPX/100.0))
      DOS = 0.97*(14.652-TERMS1+TERMS2-TERMS3)
      RETURN
      END
```

B. Input Format for Basic Streamflow and Effluent Data

80 COLUMN DATA SHEET

PROGRAM River Water Quality Simulation Model | JOB NO. | BY Dougal, M. D. | DATE

GENERAL IDENTIFICATION FOR RIVER

1 IDENT1

IDENTIFICATION FOR COMPUTER RUN — SEASON

2 IDENT2 — ISESON

EFFLUENT DATA FOR WPCP — EFFL(I), I=1,15

Card															
3	QEMGD	TEMPE	PCSE	—	BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2

RIVER WATER QUALITY DATA — RWQD(I), I=1,15

Card															
4	TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA

RIVER DISCHARGE-VELOCITY DATA — RQVD(I), I=1,15

Card															
5	QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMEN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR

RIVER ALGAE-TEMPERATURE-MISC DATA — ALGTP(I), I=1,15

Card															
6	TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX		DQESH	K2ICE	K2R

MISCELLANEOUS CONTROL AND ITERATIVE CYCLING DATA

Card															
7	IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH		IWRIT		IPLOT		NLIN	

80 COLUMN DATA SHEET

PROGRAM River Water Quality Simulation Model Computer Plotting Data	JOB NO.	BY	DATE

1–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80
FOR DISSOLVED OXYGEN RESULTS:							
8 XLAB FOR DO		YLAB FOR DO		GENERAL LABEL, DO		DAYTIME LABEL	
EXAMPLE FOR CARD 8							
MILES DOWNSTREAM		DO LEVEL, MG/L		DO PROFILE, RUN 1		DAYTIME RESULTS	
9				ADDITIONAL LABEL AVG		ADDITIONAL LABEL NIT	
EXAMPLE FOR CARD 9							
9				AVG. OF DAY & NITE		NIGHTTIME RESULTS	
FOR TOTAL BOD AND AMMONIA RESULTS							
10 XLAB FOR BODU,NH4		YLAB FOR BODU,NH4		GENERAL LABEL, PLOT		TOTAL BOD LABEL	
EXAMPLE FOR CARD 10							
MILES DOWNSTREAM		BOD AND NH4, MG/L		AVG. RESULTS, RUN 1		TOTAL BOD, CBN-AMN	
11				EFFLUENT BOD LABEL		AMMONIA LABEL	
EXAMPLE FOR CARD 11							
11				EFFLUENT BOD LEVEL		AMMONIA LEVEL	
SCALE FACTORS FOR ORDINATE AND ABSCISSA							
12	XSF	YSF	ZSF				
EXAMPLE FOR CARD 12							
12	3.0	4.0	10.0				

XXIII. APPENDIX F

A. Simulation Results for July 16-20, 1966

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.30	72.00	80.00	0.0	10.00	0.080	0.0	10.00	20.00	20.00	100.00	0.0	0.0	0.90	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
83.00	68.00	110.00	70.00	0.50	0.200	0.0	0.50	4.00	0.50	0.10	50.00	2.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
115.00	4.00	95.00	70.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.800

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
83.00	68.00	2.500	0.0	0.0	3.000	0.100	0.40	0.40	1.50	2.20	4.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
     RUN IDENT : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
     SEASON : SUMMER

 GAMMA1 =   0.90 , GAMMA2 =   0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   2.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   5.11 CFS, RIVER Q = 115.00 CFS, TOTAL Q = 120.11 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.40 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	83.0	68.0		115.0	8.19	6.13		0.50
0.0	0.37	82.5	68.2	75.4	120.1	8.13	6.15	7.14	0.90
0.01	0.58	82.6	68.2	75.4	121.0	7.99	6.13	7.06	0.86
0.02	0.80	82.6	68.2	75.4	121.8	7.89	6.10	6.99	0.81
0.03	1.01	82.6	68.1	75.4	122.7	7.80	6.08	6.94	0.77
0.04	1.23	82.6	68.1	75.4	123.5	7.74	6.07	6.90	0.73
0.05	1.45	82.6	68.1	75.4	124.4	7.69	6.05	6.87	0.69
0.06	1.66	82.7	68.1	75.4	125.3	7.67	6.03	6.85	0.66
0.07	1.88	82.7	68.1	75.4	126.1	7.65	6.02	6.84	0.63
0.08	2.10	82.7	68.1	75.4	127.0	7.66	6.00	6.83	0.60
0.09	2.32	82.7	68.1	75.4	127.9	7.67	5.98	6.83	0.57
0.10	2.54	82.7	68.1	75.4	128.8	7.70	5.96	6.83	0.56
0.11	2.76	82.8	68.1	75.4	129.7	7.73	5.94	6.84	0.55
0.12	2.98	82.8	68.1	75.4	130.5	7.78	5.92	6.85	0.54
0.13	3.20	82.8	68.1	75.4	131.4	7.84	5.89	6.87	0.53
0.14	3.42	82.8	68.1	75.4	132.3	7.90	5.87	6.89	0.52
0.15	3.64	82.8	68.1	75.4	133.2	7.97	5.85	6.91	0.51
0.16	3.86	82.8	68.1	75.4	134.1	8.05	5.83	6.94	0.50
0.17	4.09	82.8	68.1	75.4	135.0	8.13	5.80	6.97	0.50
0.18	4.31	82.8	68.1	75.4	135.9	8.22	5.78	7.00	0.50
0.19	4.53	82.8	68.1	75.5	136.8	8.31	5.76	7.03	0.50
0.20	4.76	82.9	68.1	75.5	137.7	8.40	5.74	7.07	0.50
0.21	4.98	82.9	68.1	75.5	138.6	8.50	5.72	7.11	0.50
0.22	5.21	82.9	68.0	75.5	139.5	8.59	5.70	7.14	0.50
0.23	5.44	82.9	68.0	75.5	140.4	8.69	5.68	7.18	0.50
0.24	5.66	82.9	68.0	75.5	141.3	8.78	5.66	7.22	0.50
0.25	5.89	82.9	68.0	75.5	142.2	8.88	5.64	7.26	0.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	6.12	82.9	68.0	75.5	143.1	8.97	5.62	7.29	0.50
0.27	6.35	82.9	68.0	75.5	144.0	9.05	5.61	7.33	0.50
0.28	6.58	82.9	68.0	75.5	144.9	9.14	5.59	7.36	0.50
0.29	6.81	82.9	68.0	75.5	145.8	9.22	5.58	7.40	0.50
0.30	7.04	82.9	68.0	75.5	146.8	9.29	5.56	7.43	0.50
0.31	7.27	82.9	68.0	75.5	147.7	9.36	5.55	7.46	0.50
0.32	7.50	82.9	68.0	75.5	148.6	9.42	5.54	7.48	0.50
0.33	7.73	82.9	68.0	75.5	149.5	9.48	5.53	7.51	0.50
0.34	7.96	82.9	68.0	75.5	150.5	9.53	5.52	7.53	0.50
0.35	8.19	82.9	68.0	75.5	151.4	9.57	5.52	7.54	0.50
0.36	8.43	82.9	68.0	75.5	152.3	9.60	5.51	7.56	0.50
0.37	8.66	82.9	68.0	75.5	153.3	9.63	5.50	7.57	0.50
0.38	8.90	82.9	68.0	75.5	154.2	9.64	5.50	7.57	0.50
0.39	9.13	83.0	68.0	75.5	155.2	9.65	5.50	7.58	0.50
0.40	9.37	83.0	68.0	75.5	156.1	9.65	5.50	7.57	0.50
0.41	9.60	83.0	68.0	75.5	157.0	9.65	5.50	7.57	0.50
0.42	9.84	83.0	68.0	75.5	158.0	9.63	5.50	7.56	0.50
0.43	10.08	83.0	68.0	75.5	158.9	9.61	5.50	7.56	0.50
0.44	10.31	83.0	68.0	75.5	159.9	9.58	5.50	7.54	0.50
0.45	10.55	83.0	68.0	75.5	160.8	9.55	5.51	7.53	0.50
0.46	10.79	83.0	68.0	75.5	161.8	9.50	5.52	7.51	0.50
0.47	11.03	83.0	68.0	75.5	162.7	9.46	5.53	7.49	0.50
0.48	11.27	83.0	68.0	75.5	163.7	9.41	5.54	7.47	0.50
0.49	11.51	83.0	68.0	75.5	164.7	9.35	5.55	7.45	0.50
0.50	11.75	83.0	68.0	75.5	165.6	9.29	5.57	7.43	0.50
0.51	11.99	83.0	68.0	75.5	166.6	9.23	5.58	7.41	0.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	12.23	83.0	68.0	75.5	167.6	9.16	5.60	7.38	0.50
0.53	12.48	83.0	68.0	75.5	168.5	9.10	5.62	7.36	0.50
0.54	12.72	83.0	68.0	75.5	169.5	9.03	5.65	7.34	0.50
0.55	12.96	83.0	68.0	75.5	170.5	8.96	5.67	7.32	0.50
0.56	13.21	83.0	68.0	75.5	171.5	8.90	5.70	7.30	0.50
0.57	13.45	83.0	68.0	75.5	172.4	8.84	5.72	7.28	0.50
0.58	13.70	83.0	68.0	75.5	173.4	8.78	5.75	7.26	0.50
0.59	13.94	83.0	68.0	75.5	174.4	8.72	5.77	7.25	0.50
0.60	14.19	83.0	68.0	75.5	175.4	8.67	5.80	7.23	0.50
0.61	14.44	83.0	68.0	75.5	176.4	8.62	5.82	7.22	0.50
0.62	14.68	83.0	68.0	75.5	177.4	8.58	5.84	7.21	0.50
0.63	14.93	83.0	68.0	75.5	178.3	8.54	5.86	7.20	0.50
0.64	15.18	83.0	68.0	75.5	179.3	8.51	5.88	7.19	0.50
0.65	15.43	83.0	68.0	75.5	180.3	8.48	5.89	7.18	0.50
0.66	15.68	83.0	68.0	75.5	181.3	8.45	5.91	7.18	0.50
0.67	15.93	83.0	68.0	75.5	182.3	8.43	5.92	7.17	0.50
0.68	16.18	83.0	68.0	75.5	183.3	8.41	5.93	7.17	0.50
0.69	16.43	83.0	68.0	75.5	184.3	8.39	5.94	7.16	0.50
0.70	16.68	83.0	68.0	75.5	185.3	8.37	5.94	7.16	0.50
0.71	16.93	83.0	68.0	75.5	186.3	8.36	5.95	7.15	0.50
0.72	17.18	83.0	68.0	75.5	187.4	8.35	5.96	7.15	0.50
0.73	17.43	83.0	68.0	75.5	188.4	8.34	5.96	7.15	0.50
0.74	17.69	83.0	68.0	75.5	189.4	8.33	5.97	7.15	0.50
0.75	17.94	83.0	68.0	75.5	190.4	8.32	5.97	7.14	0.50
0.76	18.20	83.0	68.0	75.5	191.4	8.31	5.97	7.14	0.50
0.77	18.45	83.0	68.0	75.5	192.4	8.31	5.97	7.14	0.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	18.71	83.0	68.0	75.5	193.5	8.30	5.97	7.14	0.50
0.79	18.96	83.0	68.0	75.5	194.5	8.30	5.97	7.14	0.50
0.80	19.22	83.0	68.0	75.5	195.5	8.29	5.97	7.13	0.50
0.81	19.47	83.0	68.0	75.5	196.5	8.29	5.97	7.13	0.50
0.82	19.73	83.0	68.0	75.5	197.6	8.29	5.97	7.13	0.50
0.83	19.99	83.0	68.0	75.5	198.6	8.28	5.97	7.13	0.50
0.84	20.25	83.0	68.0	75.5	199.6	8.28	5.97	7.13	0.50
0.85	20.51	83.0	68.0	75.5	200.7	8.28	5.97	7.13	0.50
0.86	20.77	83.0	68.0	75.5	201.7	8.28	5.97	7.12	0.50
0.87	21.03	83.0	68.0	75.5	202.7	8.28	5.97	7.12	0.50
0.88	21.29	83.0	68.0	75.5	203.8	8.28	5.96	7.12	0.50
0.89	21.55	83.0	68.0	75.5	204.8	8.28	5.96	7.12	0.50
0.90	21.81	83.0	68.0	75.5	205.9	8.28	5.96	7.12	0.50
0.91	22.07	83.0	68.0	75.5	206.9	8.28	5.95	7.12	0.50
0.92	22.33	83.0	68.0	75.5	208.0	8.28	5.95	7.12	0.50
0.93	22.60	83.0	68.0	75.5	209.0	8.28	5.95	7.11	0.50
0.94	22.86	83.0	68.0	75.5	210.1	8.28	5.94	7.11	0.50
0.95	23.12	83.0	68.0	75.5	211.1	8.29	5.94	7.11	0.50
0.96	23.39	83.0	68.0	75.5	212.2	8.29	5.93	7.11	0.50
0.97	23.65	83.0	68.0	75.5	213.2	8.29	5.93	7.11	0.50
0.98	23.92	83.0	68.0	75.5	214.3	8.29	5.93	7.11	0.50
0.99	24.18	83.0	68.0	75.5	215.4	8.29	5.92	7.11	0.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	0.50	0.91	1.41	0.68	2.09	4.00	0.50	0.10
0.0	0.37	1.12	0.98	2.09	1.24	3.33	4.68	1.33	4.35
0.01	0.58	1.08	0.99	2.08	1.17	3.25	4.50	1.30	4.01
0.02	0.80	1.05	1.00	2.06	1.11	3.17	4.33	1.28	3.70
0.03	1.01	1.02	1.02	2.04	1.05	3.09	4.16	1.26	3.41
0.04	1.23	0.99	1.03	2.02	1.00	3.02	4.06	1.23	3.15
0.05	1.45	0.96	1.04	2.00	0.95	2.95	4.00	1.21	2.91
0.06	1.66	0.93	1.05	1.99	0.90	2.89	4.00	1.19	2.68
0.07	1.88	0.91	1.06	1.97	0.86	2.83	4.00	1.17	2.48
0.08	2.10	0.88	1.07	1.96	0.82	2.77	4.00	1.15	2.29
0.09	2.32	0.86	1.09	1.94	0.78	2.72	4.00	1.13	2.12
0.10	2.54	0.83	1.10	1.93	0.74	2.67	4.00	1.11	1.96
0.11	2.76	0.81	1.11	1.91	0.70	2.62	4.00	1.09	1.81
0.12	2.98	0.78	1.12	1.90	0.67	2.57	4.00	1.07	1.67
0.13	3.20	0.76	1.13	1.89	0.64	2.53	4.00	1.05	1.55
0.14	3.42	0.74	1.14	1.88	0.61	2.49	4.00	1.03	1.43
0.15	3.64	0.72	1.15	1.87	0.58	2.45	4.00	1.01	1.33
0.16	3.86	0.70	1.16	1.86	0.56	2.41	4.00	0.99	1.23
0.17	4.09	0.68	1.17	1.85	0.53	2.38	4.00	0.98	1.14
0.18	4.31	0.66	1.17	1.84	0.51	2.34	4.00	0.96	1.05
0.19	4.53	0.64	1.18	1.83	0.49	2.31	4.00	0.94	0.98
0.20	4.76	0.63	1.19	1.82	0.47	2.28	4.00	0.93	0.90
0.21	4.98	0.61	1.20	1.81	0.45	2.26	4.00	0.91	0.84
0.22	5.21	0.59	1.21	1.80	0.43	2.23	4.00	0.90	0.78
0.23	5.44	0.58	1.22	1.79	0.41	2.20	4.00	0.88	0.72
0.24	5.66	0.56	1.22	1.79	0.39	2.18	4.00	0.87	0.67
0.25	5.89	0.55	1.23	1.78	0.38	2.16	4.00	0.85	0.62

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	6.12	0.53	1.24	1.77	0.36	2.13	4.00	0.84	0.58
0.27	6.35	0.52	1.25	1.76	0.35	2.11	4.00	0.82	0.54
0.28	6.58	0.50	1.26	1.76	0.34	2.09	4.00	0.81	0.50
0.29	6.81	0.49	1.26	1.75	0.32	2.08	4.00	0.80	0.46
0.30	7.04	0.48	1.27	1.75	0.31	2.06	4.00	0.78	0.43
0.31	7.27	0.46	1.28	1.74	0.30	2.04	4.00	0.77	0.40
0.32	7.50	0.45	1.28	1.74	0.29	2.02	4.00	0.76	0.37
0.33	7.73	0.44	1.29	1.73	0.28	2.01	4.00	0.75	0.35
0.34	7.96	0.43	1.30	1.73	0.27	1.99	4.00	0.73	0.32
0.35	8.19	0.42	1.30	1.72	0.26	1.98	4.00	0.72	0.30
0.36	8.43	0.41	1.31	1.72	0.25	1.97	4.00	0.71	0.28
0.37	8.66	0.40	1.32	1.71	0.24	1.95	4.00	0.70	0.26
0.38	8.90	0.38	1.32	1.71	0.24	1.94	4.00	0.69	0.24
0.39	9.13	0.37	1.33	1.70	0.23	1.93	4.00	0.68	0.23
0.40	9.37	0.37	1.33	1.70	0.22	1.92	4.00	0.67	0.21
0.41	9.60	0.36	1.34	1.70	0.21	1.91	4.00	0.66	0.20
0.42	9.84	0.35	1.35	1.69	0.21	1.90	4.00	0.65	0.19
0.43	10.08	0.34	1.35	1.69	0.20	1.89	4.00	0.64	0.18
0.44	10.31	0.33	1.36	1.68	0.20	1.88	4.00	0.63	0.18
0.45	10.55	0.32	1.36	1.68	0.19	1.87	4.00	0.62	0.17
0.46	10.79	0.31	1.37	1.68	0.19	1.86	4.00	0.61	0.16
0.47	11.03	0.30	1.37	1.68	0.18	1.86	4.00	0.60	0.15
0.48	11.27	0.30	1.38	1.67	0.18	1.85	4.00	0.59	0.15
0.49	11.51	0.29	1.38	1.67	0.17	1.84	4.00	0.58	0.14
0.50	11.75	0.28	1.39	1.67	0.17	1.84	4.00	0.57	0.14
0.51	11.99	0.27	1.39	1.67	0.16	1.83	4.00	0.57	0.13

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	12.23	0.27	1.40	1.66	0.16	1.82	4.00	0.56	0.13
0.53	12.48	0.26	1.40	1.66	0.16	1.82	4.00	0.56	0.12
0.54	12.72	0.25	1.40	1.66	0.15	1.81	4.00	0.56	0.12
0.55	12.96	0.25	1.41	1.66	0.15	1.81	4.00	0.55	0.11
0.56	13.21	0.24	1.41	1.65	0.15	1.80	4.00	0.55	0.11
0.57	13.45	0.24	1.42	1.65	0.14	1.80	4.00	0.55	0.11
0.58	13.70	0.23	1.42	1.65	0.14	1.79	4.00	0.54	0.10
0.59	13.94	0.22	1.43	1.65	0.14	1.79	4.00	0.54	0.10
0.60	14.19	0.22	1.43	1.65	0.13	1.78	4.00	0.54	0.10
0.61	14.44	0.21	1.43	1.65	0.13	1.78	4.00	0.53	0.10
0.62	14.68	0.21	1.44	1.64	0.13	1.77	4.00	0.53	0.10
0.63	14.93	0.20	1.44	1.64	0.13	1.77	4.00	0.52	0.10
0.64	15.18	0.20	1.45	1.64	0.12	1.77	4.00	0.52	0.10
0.65	15.43	0.19	1.45	1.64	0.12	1.76	4.00	0.52	0.10
0.66	15.68	0.19	1.45	1.64	0.12	1.76	4.00	0.52	0.10
0.67	15.93	0.18	1.46	1.64	0.12	1.76	4.00	0.51	0.10
0.68	16.18	0.18	1.46	1.64	0.12	1.75	4.00	0.51	0.10
0.69	16.43	0.17	1.46	1.64	0.11	1.75	4.00	0.51	0.10
0.70	16.68	0.17	1.47	1.64	0.11	1.75	4.00	0.50	0.10
0.71	16.93	0.17	1.47	1.63	0.11	1.75	4.00	0.50	0.10
0.72	17.18	0.16	1.47	1.63	0.11	1.74	4.00	0.50	0.10
0.73	17.43	0.16	1.48	1.63	0.11	1.74	4.00	0.50	0.10
0.74	17.69	0.15	1.48	1.63	0.11	1.74	4.00	0.50	0.10
0.75	17.94	0.15	1.48	1.63	0.10	1.74	4.00	0.50	0.10
0.76	18.20	0.15	1.49	1.63	0.10	1.73	4.00	0.50	0.10
0.77	18.45	0.14	1.49	1.63	0.10	1.73	4.00	0.50	0.10

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

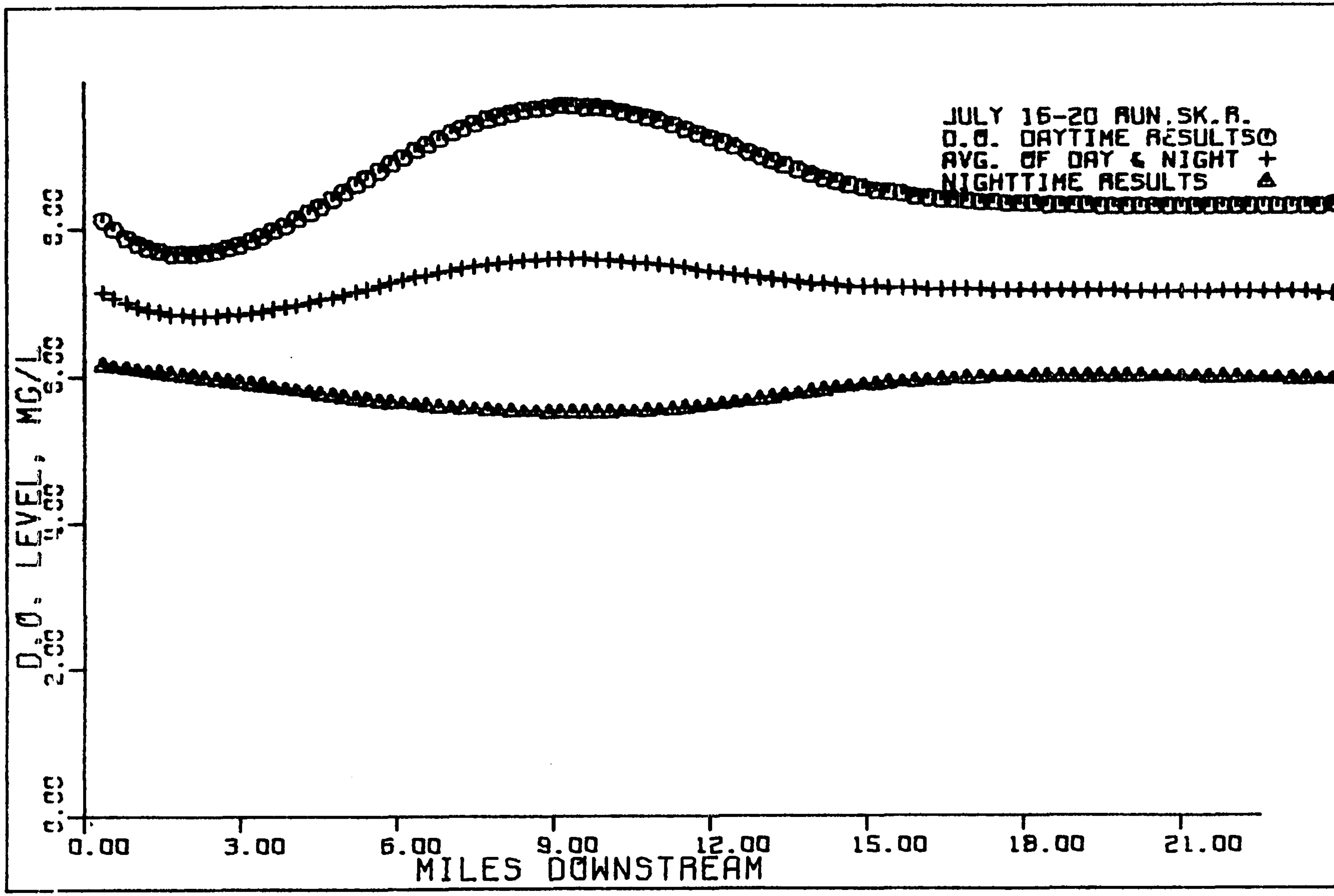
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	18.71	0.14	1.49	1.63	0.10	1.73	4.00	0.50	0.10
0.79	18.96	0.14	1.49	1.63	0.10	1.73	4.00	0.50	0.10
0.80	19.22	0.13	1.50	1.63	0.10	1.73	4.00	0.50	0.10
0.81	19.47	0.13	1.50	1.63	0.10	1.72	4.00	0.50	0.10
0.82	19.73	0.13	1.50	1.63	0.10	1.72	4.00	0.50	0.10
0.83	19.99	0.12	1.50	1.63	0.09	1.72	4.00	0.50	0.10
0.84	20.25	0.12	1.51	1.63	0.09	1.72	4.00	0.50	0.10
0.85	20.51	0.12	1.51	1.63	0.09	1.72	4.00	0.50	0.10
0.86	20.77	0.11	1.51	1.63	0.09	1.72	4.00	0.50	0.10
0.87	21.03	0.11	1.52	1.63	0.09	1.72	4.00	0.50	0.10
0.88	21.29	0.11	1.52	1.63	0.09	1.72	4.00	0.50	0.10
0.89	21.55	0.11	1.52	1.63	0.09	1.71	4.00	0.50	0.10
0.90	21.81	0.10	1.52	1.63	0.09	1.71	4.00	0.50	0.10
0.91	22.07	0.10	1.53	1.63	0.09	1.71	4.00	0.50	0.10
0.92	22.33	0.10	1.53	1.63	0.09	1.71	4.00	0.50	0.10
0.93	22.60	0.10	1.53	1.63	0.09	1.71	4.00	0.50	0.10
0.94	22.86	0.09	1.53	1.63	0.08	1.71	4.00	0.50	0.10
0.95	23.12	0.09	1.53	1.63	0.08	1.71	4.00	0.50	0.10
0.96	23.39	0.09	1.54	1.63	0.08	1.71	4.00	0.50	0.10
0.97	23.65	0.09	1.54	1.63	0.08	1.71	4.00	0.50	0.10
0.98	23.92	0.09	1.54	1.63	0.08	1.71	4.00	0.50	0.10
0.99	24.18	0.08	1.54	1.63	0.08	1.71	4.00	0.50	0.10

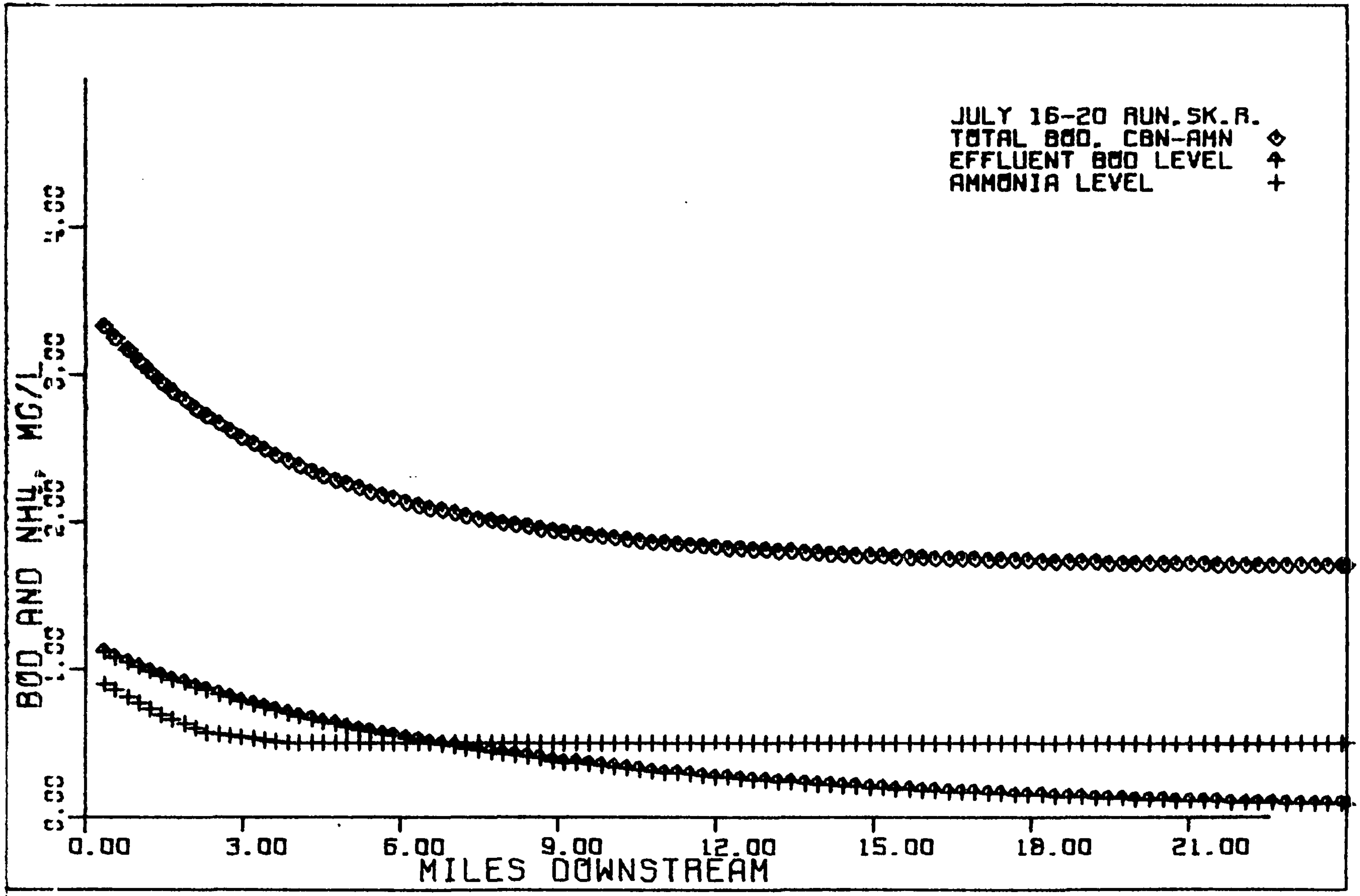
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD AND OTHER DATA FOR JULY 16-20, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.13	0.37	0.0	6.15	0.37	0.0
MINIMUM DO, MG/L	7.65	1.88	0.07	5.50	9.60	0.41
FINAL DO, MG/L	8.29	19.22	0.80	5.97	19.22	0.80
DO DEFICIT						
INITIAL, MG/L	-0.64	0.37	0.0	2.58	0.37	0.0
FINAL, MG/L	-0.85	19.22	0.80	2.78	19.22	0.80
RIVER DISCHARGE						
INITIAL, CFS	120.11	0.37	0.0	120.11	0.37	0.0
FINAL, CFS	195.50	19.22	0.80	195.50	19.22	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	82.53	0.37	0.0	68.17	0.37	0.0
FINAL, DEG F	83.00	19.22	0.80	68.00	19.22	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	1.12	0.37	0.0	1.12	0.37	0.0
FINAL BOD, MG/L	0.10	19.22	0.80	0.17	19.22	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.02	0.37	0.0	0.02	0.37	0.0
FINAL BOD IN RIVER	1.33	19.22	0.80	1.66	19.22	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	1.24	0.37	0.0	1.24	0.37	0.0
FINAL BOD, MG/L	0.06	19.22	0.80	0.14	19.22	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	3.26	0.37	0.0	3.40	0.37	0.0
FINAL VALUE, MG/L	1.49	19.22	0.80	1.97	19.22	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	0.90	0.37	0.0	0.90	0.37	0.0
FINAL VALUE, MG/L	0.50	19.22	0.80	0.50	19.22	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.68	0.37	0.0	4.68	0.37	0.0
FINAL VALUE, MG/L	4.00	19.22	0.80	4.00	19.22	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	1.33	0.37	0.0	1.33	0.37	0.0
FINAL VALUE, MG/L	0.50	19.22	0.80	0.50	19.22	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	4.35	0.37	0.0	4.35	0.37	0.0
FINAL PERCENT	0.10	19.22	0.80	0.10	19.22	0.80


JULY 16-20 RUN, SK. R.
D.O. DAYTIME RESULTS ○
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
MILES DOWNSTREAM



JULY 16-20 RUN.SK.R.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
MILES DOWNSTREAM

B. Simulation Results for August 2-3, 1966

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH

RUN IDENT : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT

SEASON : SUMMER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.00	75.00	80.00	0.0	4.00	0.080	0.0	5.00	25.00	20.00	100.00	0.0	0.0	0.80	0.50

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
80.00	61.00	122.00	65.00	1.00	0.140	0.0	0.40	0.30	0.30	0.10	40.00	2.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
15.00	2.00	100.00	60.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	1.030

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
80.00	61.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.50	2.50	4.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER

GAMMA1 =   0.80 , GAMMA2 =   0.50
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS   40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS   2.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q =   4.64 CFS, RIVER Q = 15.00 CFS, TOTAL Q = 19.64 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	80.0	61.0		15.0	9.37	6.17		0.40
0.0	0.37	78.8	64.3	71.6	19.6	8.69	6.25	7.47	1.49
0.01	0.48	78.9	64.1	71.5	19.9	8.54	6.03	7.28	1.41
0.02	0.59	78.9	64.0	71.4	20.1	8.41	5.85	7.13	1.34
0.03	0.70	79.0	63.8	71.4	20.3	8.32	5.69	7.00	1.28
0.04	0.81	79.1	63.6	71.3	20.5	8.26	5.55	6.90	1.22
0.05	0.92	79.1	63.5	71.3	20.7	8.22	5.42	6.82	1.16
0.06	1.03	79.2	63.3	71.3	21.0	8.20	5.32	6.76	1.10
0.07	1.14	79.2	63.2	71.2	21.2	8.20	5.22	6.71	1.05
0.08	1.25	79.3	63.1	71.2	21.4	8.22	5.14	6.68	1.00
0.09	1.37	79.3	63.0	71.1	21.6	8.26	5.07	6.66	0.96
0.10	1.48	79.3	62.9	71.1	21.9	8.31	5.00	6.66	0.91
0.11	1.59	79.4	62.8	71.1	22.1	8.38	4.94	6.66	0.87
0.12	1.71	79.4	62.7	71.0	22.3	8.46	4.89	6.68	0.83
0.13	1.82	79.4	62.6	71.0	22.5	8.56	4.84	6.70	0.79
0.14	1.93	79.5	62.5	71.0	22.8	8.66	4.80	6.73	0.76
0.15	2.05	79.5	62.4	70.9	23.0	8.78	4.76	6.77	0.73
0.16	2.16	79.5	62.3	70.9	23.2	8.90	4.73	6.82	0.70
0.17	2.28	79.6	62.2	70.9	23.5	9.04	4.70	6.87	0.67
0.18	2.40	79.6	62.2	70.9	23.7	9.18	4.67	6.92	0.64
0.19	2.51	79.6	62.1	70.9	23.9	9.32	4.64	6.98	0.61
0.20	2.63	79.6	62.0	70.8	24.2	9.47	4.62	7.05	0.59
0.21	2.75	79.6	62.0	70.8	24.4	9.63	4.60	7.11	0.56
0.22	2.87	79.7	61.9	70.8	24.6	9.79	4.58	7.18	0.55
0.23	2.98	79.7	61.9	70.8	24.9	9.95	4.56	7.26	0.54
0.24	3.10	79.7	61.8	70.8	25.1	10.11	4.55	7.33	0.53
0.25	3.22	79.7	61.8	70.8	25.3	10.27	4.54	7.40	0.52

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	3.34	79.7	61.7	70.7	25.6	10.43	4.53	7.48	0.51
0.27	3.46	79.7	61.7	70.7	25.8	10.59	4.52	7.55	0.50
0.28	3.58	79.8	61.7	70.7	26.1	10.75	4.51	7.63	0.49
0.29	3.70	79.8	61.6	70.7	26.3	10.90	4.50	7.70	0.48
0.30	3.82	79.8	61.6	70.7	26.6	11.04	4.50	7.77	0.48
0.31	3.95	79.8	61.6	70.7	26.8	11.18	4.49	7.84	0.47
0.32	4.07	79.8	61.5	70.7	27.0	11.32	4.49	7.90	0.46
0.33	4.19	79.8	61.5	70.7	27.3	11.44	4.48	7.96	0.45
0.34	4.31	79.8	61.5	70.7	27.5	11.56	4.48	8.02	0.45
0.35	4.44	79.8	61.4	70.6	27.8	11.67	4.48	8.08	0.44
0.36	4.56	79.9	61.4	70.6	28.0	11.77	4.48	8.13	0.43
0.37	4.69	79.9	61.4	70.6	28.3	11.86	4.48	8.17	0.43
0.38	4.81	79.9	61.4	70.6	28.5	11.94	4.49	8.21	0.42
0.39	4.94	79.9	61.4	70.6	28.8	12.00	4.49	8.25	0.41
0.40	5.06	79.9	61.3	70.6	29.0	12.06	4.49	8.28	0.41
0.41	5.19	79.9	61.3	70.6	29.3	12.10	4.50	8.30	0.40
0.42	5.31	79.9	61.3	70.6	29.5	12.14	4.50	8.32	0.40
0.43	5.44	79.9	61.3	70.6	29.8	12.16	4.51	8.33	0.40
0.44	5.57	79.9	61.3	70.6	30.0	12.16	4.51	8.34	0.40
0.45	5.69	79.9	61.2	70.6	30.3	12.16	4.52	8.34	0.40
0.46	5.82	79.9	61.2	70.6	30.5	12.14	4.53	8.33	0.40
0.47	5.95	79.9	61.2	70.6	30.8	12.11	4.53	8.32	0.40
0.48	6.08	79.9	61.2	70.6	31.1	12.07	4.54	8.31	0.40
0.49	6.21	79.9	61.2	70.6	31.3	12.02	4.55	8.29	0.40
0.50	6.34	79.9	61.2	70.6	31.6	11.96	4.56	8.26	0.40
0.51	6.47	79.9	61.2	70.6	31.8	11.89	4.57	8.23	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	6.60	79.9	61.2	70.6	32.1	11.81	4.58	8.20	0.40
0.53	6.73	79.9	61.2	70.6	32.4	11.72	4.60	8.16	0.40
0.54	6.86	79.9	61.1	70.5	32.6	11.62	4.61	8.12	0.40
0.55	6.99	79.9	61.1	70.5	32.9	11.52	4.63	8.07	0.40
0.56	7.12	80.0	61.1	70.5	33.2	11.40	4.64	8.02	0.40
0.57	7.26	80.0	61.1	70.5	33.4	11.29	4.66	7.97	0.40
0.58	7.39	80.0	61.1	70.5	33.7	11.16	4.68	7.92	0.40
0.59	7.52	80.0	61.1	70.5	33.9	11.04	4.70	7.87	0.40
0.60	7.66	80.0	61.1	70.5	34.2	10.91	4.72	7.82	0.40
0.61	7.79	80.0	61.1	70.5	34.5	10.78	4.74	7.76	0.40
0.62	7.92	80.0	61.1	70.5	34.8	10.65	4.77	7.71	0.40
0.63	8.06	80.0	61.1	70.5	35.0	10.52	4.79	7.66	0.40
0.64	8.19	80.0	61.1	70.5	35.3	10.39	4.82	7.60	0.40
0.65	8.33	80.0	61.1	70.5	35.6	10.26	4.85	7.56	0.40
0.66	8.46	80.0	61.1	70.5	35.8	10.14	4.88	7.51	0.40
0.67	8.60	80.0	61.1	70.5	36.1	10.02	4.91	7.46	0.40
0.68	8.74	80.0	61.1	70.5	36.4	9.91	4.94	7.42	0.40
0.69	8.87	80.0	61.1	70.5	36.7	9.80	4.97	7.38	0.40
0.70	9.01	80.0	61.1	70.5	36.9	9.70	5.00	7.35	0.40
0.71	9.15	80.0	61.1	70.5	37.2	9.60	5.03	7.32	0.40
0.72	9.29	80.0	61.1	70.5	37.5	9.52	5.06	7.29	0.40
0.73	9.43	80.0	61.0	70.5	37.8	9.44	5.09	7.27	0.40
0.74	9.57	80.0	61.0	70.5	38.0	9.38	5.12	7.25	0.40
0.75	9.70	80.0	61.0	70.5	38.3	9.32	5.14	7.23	0.40
0.76	9.84	80.0	61.0	70.5	38.6	9.27	5.16	7.21	0.40
0.77	9.98	80.0	61.0	70.5	38.9	9.23	5.18	7.20	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	10.12	80.0	61.0	70.5	39.2	9.19	5.20	7.19	0.40
0.79	10.27	80.0	61.0	70.5	39.4	9.16	5.21	7.18	0.40
0.80	10.41	80.0	61.0	70.5	39.7	9.13	5.23	7.18	0.40
0.81	10.55	80.0	61.0	70.5	40.0	9.11	5.24	7.17	0.40
0.82	10.69	80.0	61.0	70.5	40.3	9.09	5.25	7.17	0.40
0.83	10.83	80.0	61.0	70.5	40.6	9.07	5.26	7.16	0.40
0.84	10.98	80.0	61.0	70.5	40.9	9.05	5.27	7.16	0.40
0.85	11.12	80.0	61.0	70.5	41.1	9.04	5.28	7.16	0.40
0.86	11.26	80.0	61.0	70.5	41.4	9.03	5.29	7.16	0.40
0.87	11.41	80.0	61.0	70.5	41.7	9.02	5.29	7.16	0.40
0.88	11.55	80.0	61.0	70.5	42.0	9.01	5.30	7.16	0.40
0.89	11.69	80.0	61.0	70.5	42.3	9.01	5.30	7.16	0.40
0.90	11.84	80.0	61.0	70.5	42.6	9.00	5.31	7.16	0.40
0.91	11.98	80.0	61.0	70.5	42.9	9.00	5.31	7.16	0.40
0.92	12.13	80.0	61.0	70.5	43.2	8.99	5.32	7.16	0.40
0.93	12.28	80.0	61.0	70.5	43.5	8.99	5.32	7.16	0.40
0.94	12.42	80.0	61.0	70.5	43.7	8.99	5.33	7.16	0.40
0.95	12.57	80.0	61.0	70.5	44.0	8.98	5.33	7.16	0.40
0.96	12.72	80.0	61.0	70.5	44.3	8.98	5.33	7.16	0.40
0.97	12.86	80.0	61.0	70.5	44.6	8.98	5.34	7.16	0.40
0.98	13.01	80.0	61.0	70.5	44.9	8.98	5.34	7.16	0.40
0.99	13.16	80.0	61.0	70.5	45.2	8.98	5.34	7.16	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

		AVERAGE LEVEL OF BOD IN RIVER							
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	1.00	1.75	2.75	0.46	3.21	0.30	0.30	0.10
0.0	0.37	2.02	1.94	3.96	1.70	5.66	6.14	4.96	23.72
0.01	0.48	1.95	1.95	3.90	1.61	5.51	5.87	4.84	21.94
0.02	0.59	1.88	1.95	3.83	1.53	5.36	5.62	4.73	20.31
0.03	0.70	1.81	1.96	3.76	1.46	5.22	5.37	4.62	18.80
0.04	0.81	1.74	1.96	3.70	1.39	5.09	5.14	4.52	17.42
0.05	0.92	1.68	1.96	3.64	1.32	4.96	4.92	4.42	16.13
0.06	1.03	1.62	1.97	3.58	1.26	4.84	4.70	4.32	14.95
0.07	1.14	1.56	1.97	3.53	1.20	4.73	4.50	4.22	13.86
0.08	1.25	1.50	1.97	3.48	1.14	4.62	4.31	4.12	12.86
0.09	1.37	1.45	1.98	3.43	1.09	4.52	4.13	4.03	11.93
0.10	1.48	1.40	1.98	3.38	1.04	4.42	3.95	3.94	11.07
0.11	1.59	1.35	1.99	3.34	0.99	4.33	3.78	3.86	10.28
0.12	1.71	1.30	1.99	3.29	0.95	4.24	3.62	3.77	9.54
0.13	1.82	1.26	1.99	3.25	0.91	4.16	3.47	3.69	8.87
0.14	1.93	1.21	2.00	3.21	0.87	4.08	3.32	3.61	8.24
0.15	2.05	1.17	2.00	3.17	0.83	4.00	3.19	3.53	7.66
0.16	2.16	1.13	2.01	3.14	0.79	3.93	3.05	3.45	7.12
0.17	2.28	1.09	2.01	3.10	0.76	3.86	2.93	3.38	6.63
0.18	2.40	1.06	2.01	3.07	0.73	3.80	2.80	3.31	6.17
0.19	2.51	1.02	2.02	3.04	0.70	3.74	2.69	3.24	5.74
0.20	2.63	0.99	2.02	3.01	0.67	3.68	2.58	3.17	5.35
0.21	2.75	0.96	2.02	2.98	0.64	3.62	2.47	3.10	4.98
0.22	2.87	0.92	2.03	2.95	0.62	3.57	2.37	3.03	4.64
0.23	2.98	0.89	2.03	2.92	0.59	3.52	2.28	2.97	4.33
0.24	3.10	0.86	2.03	2.90	0.57	3.47	2.18	2.91	4.03
0.25	3.22	0.84	2.04	2.87	0.55	3.42	2.10	2.85	3.76

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	3.34	0.81	2.04	2.85	0.53	3.38	2.01	2.79	3.51
0.27	3.46	0.78	2.04	2.83	0.51	3.33	1.93	2.73	3.28
0.28	3.58	0.76	2.05	2.81	0.49	3.29	1.86	2.67	3.06
0.29	3.70	0.73	2.05	2.78	0.47	3.26	1.79	2.62	2.86
0.30	3.82	0.71	2.05	2.76	0.45	3.22	1.72	2.57	2.67
0.31	3.95	0.69	2.06	2.75	0.44	3.18	1.65	2.51	2.50
0.32	4.07	0.67	2.06	2.73	0.42	3.15	1.59	2.46	2.33
0.33	4.19	0.65	2.06	2.71	0.41	3.12	1.53	2.41	2.18
0.34	4.31	0.63	2.07	2.69	0.39	3.09	1.47	2.36	2.04
0.35	4.44	0.61	2.07	2.67	0.38	3.06	1.42	2.32	1.91
0.36	4.56	0.59	2.07	2.66	0.37	3.03	1.37	2.27	1.79
0.37	4.69	0.57	2.07	2.64	0.36	3.00	1.32	2.22	1.67
0.38	4.81	0.55	2.08	2.63	0.34	2.97	1.27	2.18	1.57
0.39	4.94	0.53	2.08	2.61	0.33	2.95	1.23	2.14	1.47
0.40	5.06	0.52	2.08	2.60	0.32	2.92	1.18	2.10	1.38
0.41	5.19	0.50	2.09	2.59	0.31	2.90	1.14	2.05	1.29
0.42	5.31	0.49	2.09	2.57	0.30	2.88	1.10	2.01	1.21
0.43	5.44	0.47	2.09	2.56	0.30	2.86	1.07	1.97	1.14
0.44	5.57	0.46	2.09	2.55	0.29	2.84	1.03	1.94	1.07
0.45	5.69	0.44	2.10	2.54	0.28	2.82	1.00	1.90	1.00
0.46	5.82	0.43	2.10	2.53	0.27	2.80	0.96	1.86	0.94
0.47	5.95	0.42	2.10	2.52	0.26	2.78	0.93	1.83	0.88
0.48	6.08	0.41	2.10	2.51	0.26	2.76	0.90	1.79	0.83
0.49	6.21	0.39	2.10	2.50	0.25	2.75	0.87	1.76	0.78
0.50	6.34	0.38	2.11	2.49	0.24	2.73	0.85	1.72	0.73
0.51	6.47	0.37	2.11	2.48	0.24	2.71	0.82	1.69	0.69

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	6.60	0.36	2.11	2.47	0.23	2.70	0.80	1.66	0.65
0.53	6.73	0.35	2.11	2.46	0.22	2.69	0.77	1.63	0.61
0.54	6.86	0.34	2.11	2.45	0.22	2.67	0.75	1.60	0.57
0.55	6.99	0.33	2.12	2.44	0.21	2.66	0.73	1.57	0.54
0.56	7.12	0.32	2.12	2.44	0.21	2.64	0.71	1.54	0.51
0.57	7.26	0.31	2.12	2.43	0.20	2.63	0.69	1.51	0.48
0.58	7.39	0.30	2.12	2.42	0.20	2.62	0.67	1.48	0.45
0.59	7.52	0.29	2.12	2.41	0.19	2.61	0.65	1.46	0.42
0.60	7.66	0.28	2.12	2.41	0.19	2.60	0.63	1.43	0.40
0.61	7.79	0.28	2.13	2.40	0.19	2.59	0.62	1.40	0.38
0.62	7.92	0.27	2.13	2.39	0.18	2.58	0.60	1.38	0.36
0.63	8.06	0.26	2.13	2.39	0.18	2.57	0.59	1.35	0.34
0.64	8.19	0.25	2.13	2.38	0.17	2.56	0.57	1.33	0.33
0.65	8.33	0.25	2.13	2.38	0.17	2.55	0.56	1.30	0.31
0.66	8.46	0.24	2.13	2.37	0.17	2.54	0.54	1.28	0.30
0.67	8.60	0.23	2.13	2.37	0.16	2.53	0.53	1.26	0.28
0.68	8.74	0.23	2.14	2.36	0.16	2.52	0.52	1.24	0.27
0.69	8.87	0.22	2.14	2.36	0.16	2.51	0.51	1.21	0.26
0.70	9.01	0.21	2.14	2.35	0.16	2.51	0.50	1.19	0.25
0.71	9.15	0.21	2.14	2.35	0.15	2.50	0.49	1.17	0.24
0.72	9.29	0.20	2.14	2.34	0.15	2.49	0.48	1.15	0.23
0.73	9.43	0.20	2.14	2.34	0.15	2.48	0.47	1.13	0.22
0.74	9.57	0.19	2.14	2.33	0.14	2.48	0.46	1.11	0.21
0.75	9.70	0.18	2.14	2.33	0.14	2.47	0.45	1.09	0.20
0.76	9.84	0.18	2.14	2.32	0.14	2.46	0.44	1.07	0.19
0.77	9.98	0.17	2.15	2.32	0.14	2.46	0.43	1.06	0.19

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

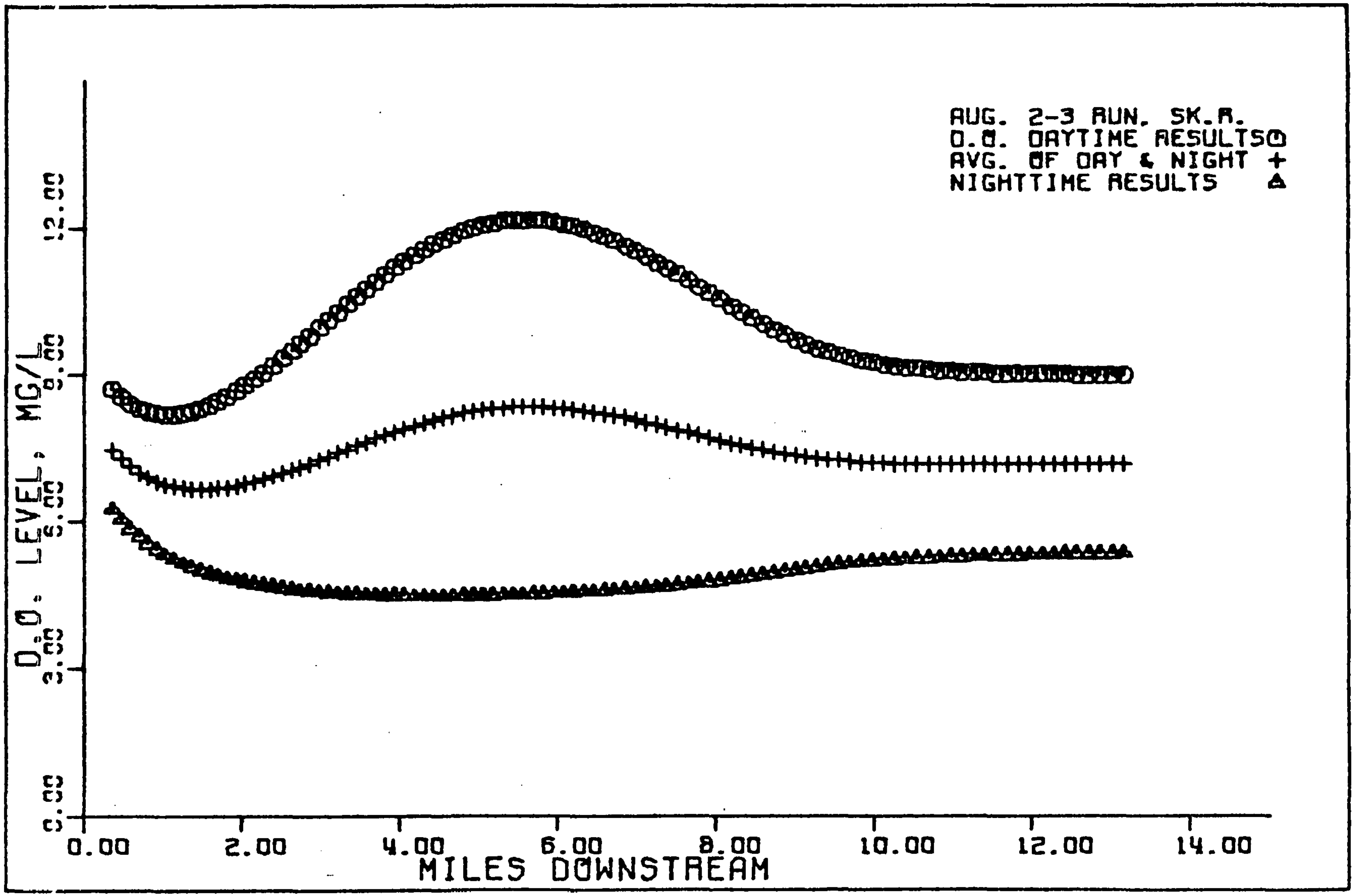
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	10.12	0.17	2.15	2.32	0.14	2.45	0.42	1.04	0.18
0.79	10.27	0.16	2.15	2.31	0.13	2.44	0.41	1.02	0.17
0.80	10.41	0.16	2.15	2.31	0.13	2.44	0.41	1.00	0.17
0.81	10.55	0.16	2.15	2.30	0.13	2.43	0.40	0.99	0.16
0.82	10.69	0.15	2.15	2.30	0.13	2.43	0.39	0.97	0.15
0.83	10.83	0.15	2.15	2.30	0.13	2.42	0.39	0.95	0.15
0.84	10.98	0.14	2.15	2.29	0.12	2.42	0.38	0.94	0.14
0.85	11.12	0.14	2.15	2.29	0.12	2.41	0.38	0.92	0.14
0.86	11.26	0.14	2.15	2.29	0.12	2.41	0.37	0.91	0.14
0.87	11.41	0.13	2.15	2.29	0.12	2.40	0.37	0.89	0.13
0.88	11.55	0.13	2.15	2.28	0.12	2.40	0.36	0.88	0.13
0.89	11.69	0.13	2.16	2.28	0.12	2.40	0.36	0.86	0.12
0.90	11.84	0.12	2.16	2.28	0.11	2.39	0.36	0.85	0.12
0.91	11.98	0.12	2.16	2.27	0.11	2.39	0.35	0.83	0.12
0.92	12.13	0.12	2.16	2.27	0.11	2.38	0.35	0.82	0.11
0.93	12.28	0.11	2.16	2.27	0.11	2.38	0.35	0.81	0.11
0.94	12.42	0.11	2.16	2.27	0.11	2.38	0.34	0.80	0.11
0.95	12.57	0.11	2.16	2.27	0.11	2.37	0.34	0.78	0.10
0.96	12.72	0.10	2.16	2.26	0.11	2.37	0.34	0.77	0.10
0.97	12.86	0.10	2.16	2.26	0.10	2.37	0.33	0.76	0.10
0.98	13.01	0.10	2.16	2.26	0.10	2.36	0.33	0.75	0.10
0.99	13.16	0.10	2.16	2.26	0.10	2.36	0.33	0.73	0.10

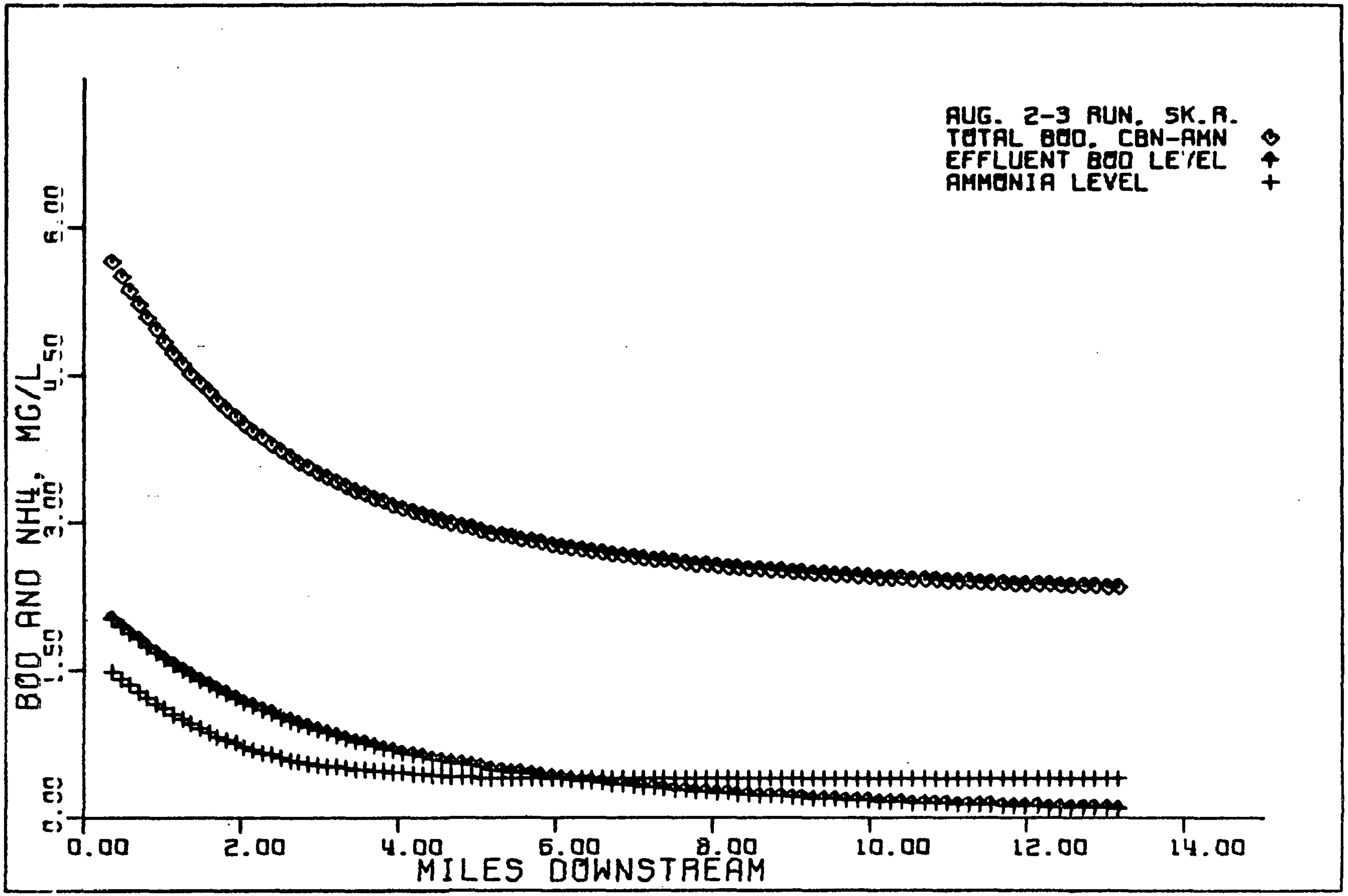
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD AND OTHER DATA FOR AUG. 2 & 3, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.69	0.37	0.0	6.25	0.37	0.0
MINIMUM DO, MG/L	8.20	1.03	0.06	4.48	4.44	0.35
FINAL DO, MG/L	9.13	10.41	0.80	5.23	10.41	0.80
DO DEFICIT						
INITIAL, MG/L	-0.91	0.37	0.0	2.88	0.37	0.0
FINAL, MG/L	-1.45	10.41	0.80	4.27	10.41	0.80
RIVER DISCHARGE						
INITIAL, CFS	19.64	0.37	0.0	19.64	0.37	0.0
FINAL, CFS	39.72	10.41	0.80	39.72	10.41	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	78.82	0.37	0.0	64.31	0.37	0.0
FINAL, DEG F	79.99	10.41	0.80	61.03	10.41	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	2.02	0.37	0.0	2.02	0.37	0.0
FINAL BOD, MG/L	0.10	10.41	0.80	0.22	10.41	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.85	10.41	0.80	2.45	10.41	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	1.70	0.37	0.0	1.70	0.37	0.0
FINAL BOD, MG/L	0.06	10.41	0.80	0.20	10.41	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	5.47	0.37	0.0	5.84	0.37	0.0
FINAL VALUE, MG/L	2.01	10.41	0.80	2.87	10.41	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	1.49	0.37	0.0	1.49	0.37	0.0
FINAL VALUE, MG/L	0.40	10.41	0.80	0.40	10.41	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	6.14	0.37	0.0	6.14	0.37	0.0
FINAL VALUE, MG/L	0.31	10.41	0.80	0.50	10.41	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.96	0.37	0.0	4.96	0.37	0.0
FINAL VALUE, MG/L	0.77	10.41	0.80	1.23	10.41	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	23.72	0.37	0.0	23.72	0.37	0.0
FINAL PERCENT	0.10	10.41	0.80	0.23	10.41	0.80


AUG. 2-3 RUN. SK.R.
D.O. DAYTIME RESULTS ○
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM



AUG. 2-3 RUN. SK.R.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
1.50
3.00
4.50
6.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

C. Simulation Results for August 17-19, 1966

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
2.90	70.00	50.00	0.0	70.00	0.080	0.0	27.00	2.00	30.00	100.00	0.0	0.0	0.72	0.80

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
84.00	61.00	135.00	70.00	1.00	0.110	0.0	0.10	0.10	0.50	0.10	100.00	2.00	0.50	0.40

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
11.00	1.80	100.00	60.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	1.630

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
84.00	61.00	2.500	0.0	0.0	3.700	0.100	0.40	1.30	2.20	3.00	3.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

      INPUT DATA FOR THIS ANALYSIS

      STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
      RUN IDENT : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
      SEASON : SUMMER

 GAMMA1 =   0.72 , GAMMA2 =   0.80
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES



IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS   100.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   2.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   4.49 CFS, RIVER Q =  11.00 CFS, TOTAL Q =  15.49 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   1.30 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	84.0	61.0		11.0	9.95	6.65		0.10
0.0	0.37	79.9	63.6	71.8	15.5	8.30	5.96	7.13	7.90
0.01	0.47	80.2	63.5	71.8	15.7	6.72	5.20	5.96	7.47
0.02	0.57	80.4	63.3	71.9	15.8	5.44	4.28	4.86	7.07
0.03	0.67	80.6	63.2	71.9	16.0	4.46	3.50	3.98	6.69
0.04	0.77	80.8	63.1	71.9	16.2	3.72	2.86	3.29	6.33
0.05	0.87	81.0	63.0	72.0	16.4	3.19	2.32	2.75	6.00
0.06	0.97	81.1	62.8	72.0	16.6	2.84	1.87	2.36	5.68
0.07	1.08	81.3	62.7	72.0	16.8	2.65	1.51	2.08	5.38
0.08	1.18	81.4	62.6	72.0	16.9	2.60	1.23	1.91	5.11
0.09	1.28	81.6	62.6	72.1	17.1	2.65	1.02	1.84	4.86
0.10	1.38	81.7	62.5	72.1	17.3	2.81	0.86	1.83	4.63
0.11	1.49	81.8	62.4	72.1	17.5	3.04	0.73	1.89	4.41
0.12	1.59	82.0	62.3	72.1	17.7	3.35	0.63	1.99	4.21
0.13	1.70	82.1	62.2	72.2	17.9	3.72	0.54	2.13	4.02
0.14	1.80	82.2	62.2	72.2	18.1	4.13	0.47	2.30	3.84
0.15	1.91	82.3	62.1	72.2	18.3	4.58	0.41	2.50	3.67
0.16	2.01	82.4	62.0	72.2	18.4	5.07	0.36	2.72	3.52
0.17	2.12	82.5	62.0	72.2	18.6	5.58	0.32	2.95	3.37
0.18	2.23	82.6	61.9	72.2	18.8	6.12	0.29	3.20	3.23
0.19	2.33	82.6	61.9	72.3	19.0	6.66	0.26	3.46	3.10
0.20	2.44	82.7	61.8	72.3	19.2	7.22	0.23	3.73	2.97
0.21	2.55	82.8	61.8	72.3	19.4	7.78	0.20	3.99	2.85
0.22	2.66	82.9	61.7	72.3	19.6	8.34	0.18	4.26	2.74
0.23	2.77	82.9	61.7	72.3	19.8	8.90	0.15	4.53	2.63
0.24	2.88	83.0	61.7	72.3	20.0	9.45	0.13	4.79	2.53
0.25	2.99	83.0	61.6	72.3	20.2	10.00	0.11	5.05	2.44

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	3.10	83.1	61.6	72.3	20.4	10.52	0.09	5.31	2.34
0.27	3.21	83.1	61.6	72.3	20.6	11.03	0.07	5.55	2.26
0.28	3.32	83.2	61.5	72.4	20.8	11.52	0.06	5.79	2.18
0.29	3.43	83.2	61.5	72.4	21.0	11.99	0.05	6.02	2.10
0.30	3.54	83.3	61.5	72.4	21.2	12.44	0.04	6.24	2.02
0.31	3.65	83.3	61.4	72.4	21.4	12.86	0.03	6.45	1.95
0.32	3.76	83.4	61.4	72.4	21.6	13.25	0.03	6.64	1.89
0.33	3.88	83.4	61.4	72.4	21.8	13.61	0.03	6.82	1.82
0.34	3.99	83.4	61.4	72.4	22.0	13.93	0.04	6.99	1.76
0.35	4.10	83.5	61.3	72.4	22.2	14.23	0.05	7.14	1.70
0.36	4.22	83.5	61.3	72.4	22.4	14.49	0.06	7.27	1.65
0.37	4.33	83.5	61.3	72.4	22.6	14.72	0.08	7.40	1.60
0.38	4.45	83.5	61.3	72.4	22.8	14.91	0.10	7.50	1.54
0.39	4.56	83.6	61.3	72.4	23.0	15.06	0.12	7.59	1.50
0.40	4.68	83.6	61.3	72.4	23.2	15.18	0.16	7.67	1.45
0.41	4.79	83.6	61.2	72.4	23.4	15.26	0.19	7.73	1.41
0.42	4.91	83.6	61.2	72.4	23.7	15.31	0.24	7.77	1.36
0.43	5.02	83.7	61.2	72.4	23.9	15.32	0.29	7.80	1.32
0.44	5.14	83.7	61.2	72.4	24.1	15.30	0.34	7.82	1.28
0.45	5.26	83.7	61.2	72.4	24.3	15.24	0.40	7.82	1.25
0.46	5.38	83.7	61.2	72.4	24.5	15.15	0.47	7.81	1.21
0.47	5.50	83.7	61.2	72.5	24.7	15.04	0.55	7.79	1.18
0.48	5.61	83.7	61.2	72.5	24.9	14.89	0.63	7.76	1.14
0.49	5.73	83.8	61.2	72.5	25.1	14.72	0.73	7.72	1.11
0.50	5.85	83.8	61.1	72.5	25.4	14.53	0.83	7.68	1.09
0.51	5.97	83.8	61.1	72.5	25.6	14.31	0.95	7.63	1.05

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	6.09	83.8	61.1	72.5	25.8	14.08	1.07	7.58	1.01
0.53	6.21	83.8	61.1	72.5	26.0	13.83	1.21	7.52	0.98
0.54	6.33	83.8	61.1	72.5	26.2	13.56	1.35	7.46	0.95
0.55	6.45	83.8	61.1	72.5	26.4	13.28	1.51	7.40	0.92
0.56	6.58	83.8	61.1	72.5	26.7	13.00	1.67	7.33	0.89
0.57	6.70	83.8	61.1	72.5	26.9	12.71	1.84	7.27	0.86
0.58	6.82	83.9	61.1	72.5	27.1	12.42	2.01	7.21	0.83
0.59	6.94	83.9	61.1	72.5	27.3	12.12	2.19	7.16	0.81
0.60	7.07	83.9	61.1	72.5	27.5	11.83	2.38	7.11	0.78
0.61	7.19	83.9	61.1	72.5	27.8	11.55	2.58	7.07	0.76
0.62	7.31	83.9	61.1	72.5	28.0	11.28	2.77	7.03	0.73
0.63	7.44	83.9	61.1	72.5	28.2	11.02	2.97	7.00	0.71
0.64	7.56	83.9	61.1	72.5	28.4	10.77	3.17	6.97	0.69
0.65	7.69	83.9	61.1	72.5	28.7	10.54	3.36	6.95	0.67
0.66	7.81	83.9	61.1	72.5	28.9	10.33	3.55	6.94	0.65
0.67	7.94	83.9	61.1	72.5	29.1	10.14	3.73	6.93	0.63
0.68	8.06	83.9	61.1	72.5	29.3	9.97	3.89	6.93	0.61
0.69	8.19	83.9	61.0	72.5	29.6	9.83	4.04	6.94	0.59
0.70	8.32	83.9	61.0	72.5	29.8	9.71	4.18	6.94	0.57
0.71	8.44	83.9	61.0	72.5	30.0	9.60	4.31	6.96	0.56
0.72	8.57	83.9	61.0	72.5	30.3	9.52	4.42	6.97	0.54
0.73	8.70	83.9	61.0	72.5	30.5	9.44	4.53	6.99	0.53
0.74	8.83	83.9	61.0	72.5	30.7	9.38	4.63	7.00	0.51
0.75	8.96	83.9	61.0	72.5	30.9	9.33	4.72	7.02	0.50
0.76	9.09	83.9	61.0	72.5	31.2	9.28	4.81	7.04	0.48
0.77	9.21	84.0	61.0	72.5	31.4	9.24	4.88	7.06	0.47

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	9.34	84.0	61.0	72.5	31.6	9.21	4.95	7.08	0.45
0.79	9.47	84.0	61.0	72.5	31.9	9.19	5.02	7.10	0.44
0.80	9.60	84.0	61.0	72.5	32.1	9.17	5.08	7.12	0.43
0.81	9.74	84.0	61.0	72.5	32.3	9.15	5.14	7.14	0.42
0.82	9.87	84.0	61.0	72.5	32.6	9.13	5.19	7.16	0.41
0.83	10.00	84.0	61.0	72.5	32.8	9.12	5.24	7.18	0.39
0.84	10.13	84.0	61.0	72.5	33.1	9.11	5.29	7.20	0.38
0.85	10.26	84.0	61.0	72.5	33.3	9.10	5.33	7.22	0.37
0.86	10.39	84.0	61.0	72.5	33.5	9.10	5.37	7.24	0.36
0.87	10.53	84.0	61.0	72.5	33.8	9.09	5.41	7.25	0.35
0.88	10.66	84.0	61.0	72.5	34.0	9.09	5.45	7.27	0.34
0.89	10.79	84.0	61.0	72.5	34.3	9.09	5.48	7.29	0.33
0.90	10.93	84.0	61.0	72.5	34.5	9.09	5.51	7.30	0.33
0.91	11.06	84.0	61.0	72.5	34.7	9.09	5.55	7.32	0.32
0.92	11.20	84.0	61.0	72.5	35.0	9.09	5.57	7.33	0.31
0.93	11.33	84.0	61.0	72.5	35.2	9.09	5.60	7.34	0.30
0.94	11.47	84.0	61.0	72.5	35.5	9.09	5.63	7.36	0.29
0.95	11.60	84.0	61.0	72.5	35.7	9.09	5.65	7.37	0.29
0.96	11.74	84.0	61.0	72.5	36.0	9.09	5.67	7.38	0.28
0.97	11.88	84.0	61.0	72.5	36.2	9.09	5.69	7.39	0.27
0.98	12.01	84.0	61.0	72.5	36.4	9.10	5.72	7.41	0.26
0.99	12.15	84.0	61.0	72.5	36.7	9.10	5.73	7.42	0.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	1.00	3.25	4.25	0.15	4.40	0.10	0.50	0.10
0.0	0.37	25.00	4.30	29.30	11.52	40.82	0.65	9.05	29.05
0.01	0.47	23.83	4.27	28.10	10.90	39.00	0.75	8.84	26.85
0.02	0.57	22.56	4.20	26.75	10.32	37.07	0.84	8.63	24.81
0.03	0.67	21.36	4.13	25.49	9.76	35.25	0.92	8.42	22.94
0.04	0.77	20.23	4.07	24.30	9.24	33.54	0.99	8.23	21.21
0.05	0.87	19.18	4.01	23.19	8.75	31.94	1.05	8.03	19.61
0.06	0.97	18.19	3.96	22.15	8.29	30.43	1.10	7.85	18.14
0.07	1.08	17.26	3.91	21.17	7.85	29.02	1.13	7.66	16.79
0.08	1.18	16.39	3.86	20.25	7.46	27.70	1.15	7.48	15.54
0.09	1.28	15.57	3.82	19.38	7.09	26.47	1.16	7.31	14.39
0.10	1.38	14.80	3.78	18.57	6.75	25.32	1.16	7.14	13.32
0.11	1.49	14.07	3.74	17.81	6.43	24.24	1.15	6.98	12.34
0.12	1.59	13.38	3.70	17.09	6.14	23.23	1.14	6.82	11.44
0.13	1.70	12.74	3.67	16.41	5.86	22.27	1.12	6.66	10.61
0.14	1.80	12.13	3.64	15.77	5.61	21.37	1.10	6.51	9.84
0.15	1.91	11.56	3.61	15.17	5.36	20.53	1.08	6.37	9.13
0.16	2.01	11.03	3.59	14.61	5.13	19.75	1.06	6.22	8.49
0.17	2.12	10.53	3.57	14.09	4.92	19.01	1.03	6.09	7.90
0.18	2.23	10.06	3.55	13.61	4.71	18.32	1.01	5.95	7.36
0.19	2.33	9.62	3.53	13.15	4.52	17.67	0.98	5.82	6.86
0.20	2.44	9.20	3.52	12.72	4.33	17.05	0.96	5.70	6.41
0.21	2.55	8.81	3.51	12.31	4.16	16.48	0.93	5.57	5.99
0.22	2.66	8.44	3.49	11.93	4.00	15.93	0.91	5.45	5.60
0.23	2.77	8.09	3.49	11.58	3.84	15.42	0.88	5.34	5.24
0.24	2.88	7.76	3.48	11.24	3.69	14.93	0.85	5.23	4.91
0.25	2.99	7.45	3.47	10.92	3.55	14.47	0.83	5.12	4.61

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	3.10	7.15	3.47	10.62	3.42	14.04	0.80	5.01	4.33
0.27	3.21	6.87	3.46	10.34	3.29	13.63	0.78	4.91	4.07
0.28	3.32	6.61	3.46	10.07	3.18	13.24	0.75	4.81	3.83
0.29	3.43	6.35	3.46	9.81	3.06	12.88	0.73	4.71	3.60
0.30	3.54	6.11	3.46	9.57	2.95	12.53	0.70	4.61	3.40
0.31	3.65	5.89	3.46	9.34	2.85	12.19	0.68	4.52	3.20
0.32	3.76	5.67	3.46	9.12	2.75	11.88	0.65	4.43	3.02
0.33	3.88	5.46	3.46	8.92	2.66	11.58	0.63	4.34	2.85
0.34	3.99	5.26	3.46	8.72	2.57	11.29	0.61	4.26	2.70
0.35	4.10	5.07	3.46	8.53	2.49	11.01	0.59	4.17	2.55
0.36	4.22	4.89	3.46	8.35	2.41	10.75	0.57	4.09	2.41
0.37	4.33	4.71	3.46	8.17	2.33	10.50	0.55	4.01	2.28
0.38	4.45	4.54	3.46	8.00	2.25	10.26	0.53	3.93	2.15
0.39	4.56	4.38	3.46	7.84	2.18	10.02	0.51	3.85	2.04
0.40	4.68	4.23	3.46	7.68	2.12	9.80	0.49	3.78	1.93
0.41	4.79	4.08	3.45	7.53	2.05	9.58	0.47	3.71	1.82
0.42	4.91	3.93	3.45	7.38	1.99	9.37	0.45	3.63	1.72
0.43	5.02	3.79	3.45	7.24	1.93	9.17	0.43	3.56	1.62
0.44	5.14	3.65	3.44	7.09	1.87	8.97	0.42	3.49	1.53
0.45	5.26	3.52	3.44	6.95	1.82	8.77	0.40	3.42	1.44
0.46	5.38	3.39	3.43	6.82	1.77	8.58	0.38	3.35	1.36
0.47	5.50	3.26	3.42	6.68	1.72	8.40	0.37	3.29	1.28
0.48	5.61	3.14	3.41	6.55	1.67	8.22	0.35	3.22	1.20
0.49	5.73	3.03	3.40	6.43	1.62	8.05	0.34	3.16	1.13
0.50	5.85	2.92	3.39	6.31	1.57	7.88	0.33	3.10	1.06
0.51	5.97	2.81	3.38	6.19	1.53	7.72	0.31	3.03	1.00

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	6.09	2.71	3.38	6.08	1.48	7.56	0.30	2.97	0.94
0.53	6.21	2.61	3.37	5.98	1.44	7.41	0.29	2.92	0.89
0.54	6.33	2.51	3.36	5.88	1.39	7.27	0.28	2.86	0.84
0.55	6.45	2.42	3.36	5.78	1.35	7.13	0.28	2.80	0.79
0.56	6.58	2.34	3.35	5.69	1.30	6.99	0.27	2.75	0.74
0.57	6.70	2.26	3.34	5.60	1.26	6.86	0.27	2.70	0.70
0.58	6.82	2.18	3.34	5.51	1.22	6.73	0.26	2.65	0.66
0.59	6.94	2.10	3.33	5.43	1.17	6.61	0.26	2.59	0.63
0.60	7.07	2.03	3.33	5.35	1.13	6.49	0.26	2.55	0.59
0.61	7.19	1.96	3.32	5.28	1.09	6.37	0.25	2.50	0.56
0.62	7.31	1.89	3.32	5.21	1.05	6.26	0.25	2.45	0.54
0.63	7.44	1.82	3.31	5.14	1.02	6.16	0.25	2.40	0.51
0.64	7.56	1.76	3.31	5.07	0.98	6.05	0.25	2.36	0.49
0.65	7.69	1.70	3.31	5.01	0.95	5.96	0.24	2.31	0.46
0.66	7.81	1.64	3.30	4.94	0.92	5.86	0.24	2.27	0.44
0.67	7.94	1.59	3.30	4.88	0.89	5.77	0.24	2.23	0.42
0.68	8.06	1.53	3.29	4.83	0.86	5.68	0.23	2.19	0.40
0.69	3.19	1.48	3.29	4.77	0.83	5.60	0.23	2.15	0.38
0.70	8.32	1.43	3.29	4.72	0.80	5.52	0.23	2.11	0.36
0.71	8.44	1.38	3.28	4.67	0.77	5.44	0.23	2.07	0.35
0.72	8.57	1.34	3.28	4.62	0.75	5.37	0.22	2.03	0.33
0.73	8.70	1.29	3.28	4.57	0.72	5.29	0.22	2.00	0.31
0.74	8.83	1.25	3.28	4.53	0.70	5.22	0.22	1.96	0.30
0.75	8.96	1.21	3.27	4.48	0.68	5.16	0.22	1.93	0.29
0.76	9.09	1.17	3.27	4.44	0.65	5.09	0.21	1.89	0.27
0.77	9.21	1.13	3.27	4.40	0.63	5.03	0.21	1.86	0.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

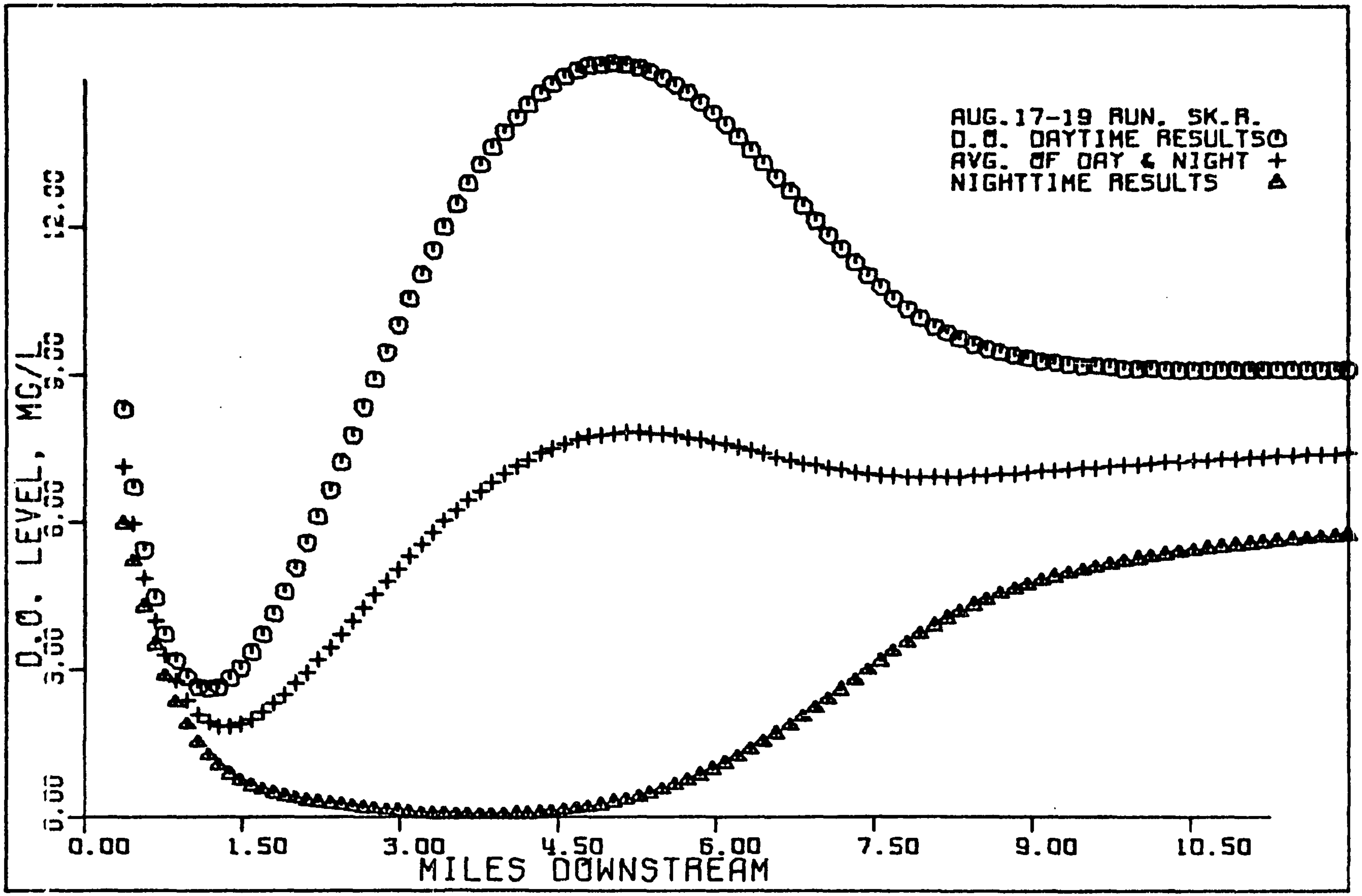
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	9.34	1.10	3.26	4.36	0.61	4.97	0.21	1.82	0.25
0.79	9.47	1.06	3.26	4.32	0.59	4.91	0.21	1.79	0.24
0.80	9.60	1.03	3.26	4.29	0.57	4.86	0.20	1.76	0.23
0.81	9.74	0.99	3.26	4.25	0.55	4.80	0.20	1.73	0.22
0.82	9.87	0.96	3.25	4.22	0.54	4.75	0.20	1.70	0.21
0.83	10.00	0.93	3.25	4.18	0.52	4.70	0.19	1.67	0.20
0.84	10.13	0.90	3.25	4.15	0.50	4.65	0.19	1.64	0.20
0.85	10.26	0.87	3.25	4.12	0.49	4.61	0.19	1.61	0.19
0.86	10.39	0.85	3.25	4.09	0.47	4.56	0.19	1.59	0.18
0.87	10.53	0.82	3.24	4.06	0.46	4.52	0.19	1.56	0.17
0.88	10.66	0.79	3.24	4.03	0.44	4.48	0.19	1.53	0.17
0.89	10.79	0.77	3.24	4.01	0.43	4.43	0.19	1.51	0.16
0.90	10.93	0.74	3.24	3.98	0.41	4.40	0.18	1.48	0.16
0.91	11.06	0.72	3.24	3.96	0.40	4.36	0.18	1.46	0.15
0.92	11.20	0.70	3.23	3.93	0.39	4.32	0.18	1.43	0.15
0.93	11.33	0.68	3.23	3.91	0.38	4.29	0.18	1.41	0.14
0.94	11.47	0.66	3.23	3.89	0.36	4.25	0.18	1.38	0.14
0.95	11.60	0.64	3.23	3.86	0.35	4.22	0.18	1.36	0.13
0.96	11.74	0.62	3.23	3.84	0.34	4.18	0.17	1.34	0.13
0.97	11.88	0.60	3.22	3.82	0.33	4.15	0.17	1.32	0.12
0.98	12.01	0.58	3.22	3.80	0.32	4.12	0.17	1.30	0.12
0.99	12.15	0.56	3.22	3.78	0.31	4.09	0.17	1.27	0.12

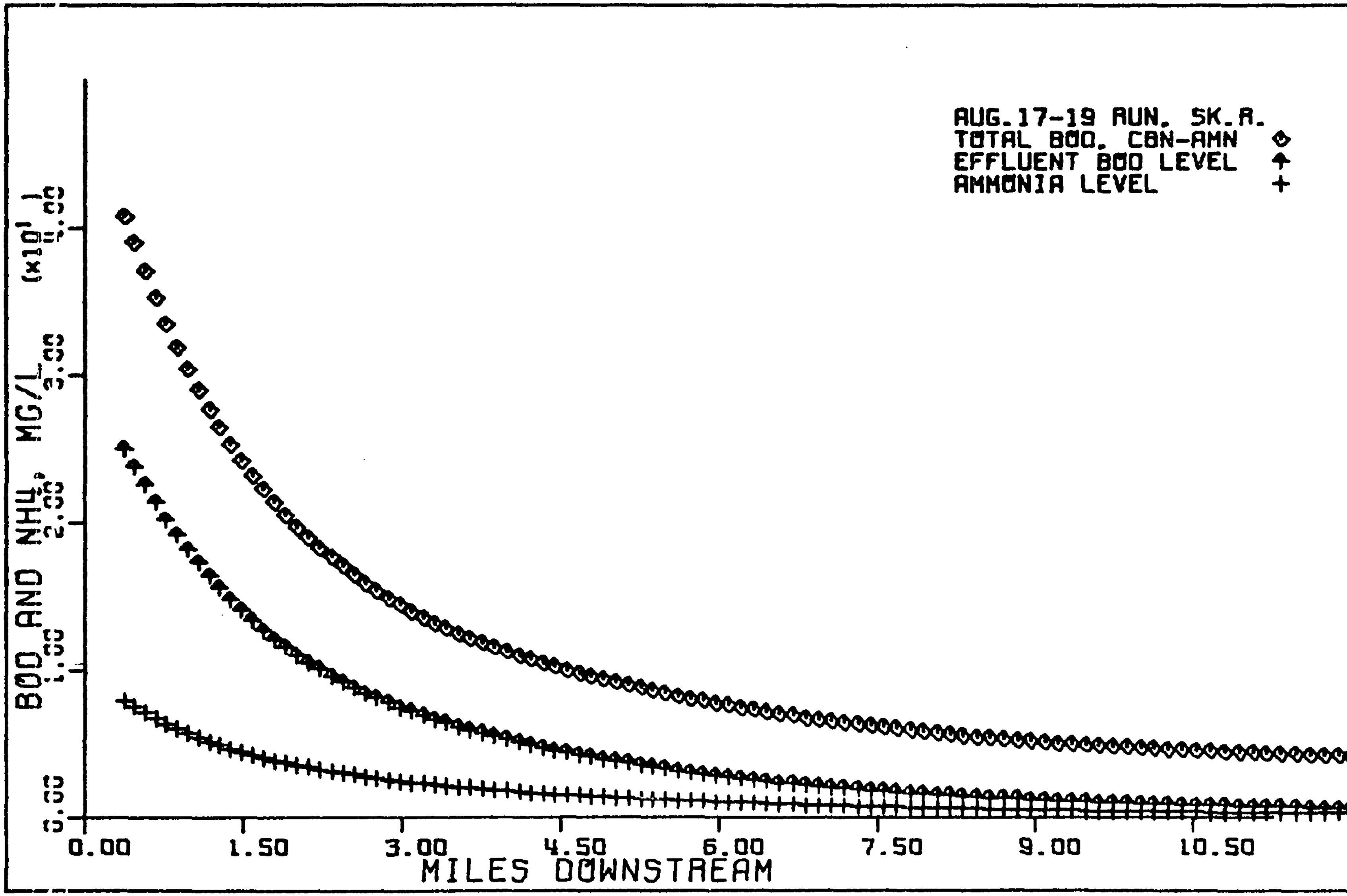
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD AND OTHER DATA FOR AUG. 17-19, 1966, PRIMARY EFFLUENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.30	0.37	0.0	5.96	0.37	0.0
MINIMUM DO, MG/L	2.60	1.18	0.08	0.03	3.76	0.32
FINAL DO, MG/L	9.17	9.60	0.80	5.08	9.60	0.80
DO DEFICIT						
INITIAL, MG/L	-0.62	0.37	0.0	3.24	0.37	0.0
FINAL, MG/L	-1.79	9.60	0.80	4.41	9.60	0.80
RIVER DISCHARGE						
INITIAL, CFS	15.49	0.37	0.0	15.49	0.37	0.0
FINAL, CFS	32.11	9.60	0.80	32.11	9.60	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	79.94	0.37	0.0	63.61	0.37	0.0
FINAL, DEG F	83.96	9.60	0.80	61.03	9.60	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	25.00	0.37	0.0	25.00	0.37	0.0
FINAL BOD, MG/L	0.44	9.60	0.80	1.61	9.60	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.12	0.37	0.0	0.12	0.37	0.0
FINAL BOD IN RIVER	2.65	9.60	0.80	3.87	9.60	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	11.52	0.37	0.0	11.52	0.37	0.0
FINAL BOD, MG/L	0.04	9.60	0.80	1.11	9.60	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	39.77	0.37	0.0	41.87	0.37	0.0
FINAL VALUE, MG/L	3.13	9.60	0.80	6.59	9.60	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	7.90	0.37	0.0	7.90	0.37	0.0
FINAL VALUE, MG/L	0.10	9.60	0.80	0.76	9.60	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	0.65	0.37	0.0	0.65	0.37	0.0
FINAL VALUE, MG/L	0.11	9.60	0.80	0.29	9.60	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	9.05	0.37	0.0	9.05	0.37	0.0
FINAL VALUE, MG/L	1.22	9.60	0.80	2.30	9.60	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	29.05	0.37	0.0	29.05	0.37	0.0
FINAL PERCENT	0.10	9.60	0.80	0.36	9.60	0.80


AUG.17-19 RUN. SK.R.
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM


AUG.17-19 RUN. SK.R.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10^1)
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM

D. Simulation Results for August 29-31, 1966

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.10	72.00	80.00	0.0	5.00	0.080	0.0	15.50	4.40	30.00	100.00	0.0	0.0	0.75	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
86.00	74.00	140.00	72.00	1.00	0.120	0.0	0.50	0.30	0.40	0.10	60.00	2.00	0.10	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
9.20	1.20	100.00	65.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	1.380

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
86.00	74.00	2.500	0.0	0.0	2.000	0.100	0.40	1.50	2.30	4.00	3.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                    AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION      IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
     RUN IDENT : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
     SEASON : SUMMER

 GAMMA1 =    0.75  , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS     60.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR    0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS    2.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    4.80 CFS, RIVER Q =    9.20 CFS, TOTAL Q =  14.00 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   1.50 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	86.0	74.0		9.2	10.10	5.90		0.50
0.0	0.37	81.2	73.3	77.3	14.0	8.93	6.17	7.55	5.64
0.01	0.47	81.5	73.4	77.4	14.1	8.30	5.56	6.93	5.31
0.02	0.56	81.7	73.4	77.6	14.2	7.79	5.04	6.42	4.99
0.03	0.66	82.0	73.4	77.7	14.3	7.41	4.61	6.01	4.70
0.04	0.76	82.2	73.5	77.8	14.5	7.12	4.26	5.69	4.42
0.05	0.85	82.4	73.5	77.9	14.6	6.93	3.97	5.45	4.15
0.06	0.95	82.6	73.5	78.1	14.7	6.83	3.74	5.28	3.91
0.07	1.05	82.8	73.5	78.2	14.8	6.79	3.56	5.17	3.67
0.08	1.15	83.0	73.6	78.3	14.9	6.82	3.41	5.12	3.45
0.09	1.24	83.1	73.6	78.4	15.0	6.91	3.30	5.11	3.24
0.10	1.34	83.3	73.6	78.5	15.2	7.04	3.22	5.13	3.05
0.11	1.44	83.5	73.6	78.5	15.3	7.22	3.17	5.20	2.87
0.12	1.54	83.6	73.7	78.6	15.4	7.44	3.13	5.29	2.70
0.13	1.64	83.7	73.7	78.7	15.5	7.69	3.11	5.40	2.53
0.14	1.74	83.9	73.7	78.8	15.6	7.96	3.11	5.54	2.38
0.15	1.84	84.0	73.7	78.8	15.8	8.26	3.12	5.69	2.24
0.16	1.94	84.1	73.7	78.9	15.9	8.57	3.14	5.86	2.11
0.17	2.04	84.2	73.7	79.0	16.0	8.89	3.17	6.03	1.98
0.18	2.14	84.3	73.8	79.0	16.1	9.22	3.21	6.21	1.86
0.19	2.24	84.4	73.8	79.1	16.2	9.54	3.25	6.40	1.75
0.20	2.34	84.5	73.8	79.1	16.4	9.87	3.30	6.58	1.65
0.21	2.44	84.6	73.8	79.2	16.5	10.19	3.35	6.77	1.55
0.22	2.55	84.6	73.8	79.2	16.6	10.50	3.40	6.95	1.46
0.23	2.65	84.7	73.8	79.3	16.7	10.79	3.46	7.13	1.38
0.24	2.75	84.8	73.8	79.3	16.9	11.07	3.52	7.29	1.30
0.25	2.85	84.9	73.8	79.3	17.0	11.33	3.57	7.45	1.22

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.96	84.9	73.8	79.4	17.1	11.57	3.63	7.60	1.15
0.27	3.06	85.0	73.9	79.4	17.2	11.78	3.69	7.74	1.08
0.28	3.16	85.0	73.9	79.5	17.4	11.96	3.75	7.86	1.02
0.29	3.27	85.1	73.9	79.5	17.5	12.12	3.81	7.97	0.96
0.30	3.37	85.1	73.9	79.5	17.6	12.25	3.87	8.06	0.91
0.31	3.48	85.2	73.9	79.5	17.7	12.35	3.93	8.14	0.86
0.32	3.58	85.2	73.9	79.6	17.9	12.42	3.99	8.20	0.81
0.33	3.69	85.3	73.9	79.6	18.0	12.46	4.05	8.25	0.78
0.34	3.79	85.3	73.9	79.6	18.1	12.47	4.11	8.29	0.75
0.35	3.90	85.4	73.9	79.6	18.2	12.45	4.16	8.31	0.73
0.36	4.00	85.4	73.9	79.7	18.4	12.41	4.22	8.31	0.71
0.37	4.11	85.4	73.9	79.7	18.5	12.34	4.27	8.31	0.68
0.38	4.21	85.5	73.9	79.7	18.6	12.25	4.33	8.29	0.66
0.39	4.32	85.5	73.9	79.7	18.7	12.14	4.38	8.26	0.64
0.40	4.43	85.5	73.9	79.7	18.9	12.01	4.44	8.22	0.63
0.41	4.54	85.5	73.9	79.7	19.0	11.86	4.49	8.18	0.61
0.42	4.64	85.6	73.9	79.8	19.1	11.71	4.55	8.13	0.59
0.43	4.75	85.6	73.9	79.8	19.3	11.54	4.60	8.07	0.58
0.44	4.86	85.6	73.9	79.8	19.4	11.37	4.65	8.01	0.56
0.45	4.97	85.6	73.9	79.8	19.5	11.19	4.71	7.95	0.55
0.46	5.08	85.7	74.0	79.8	19.6	11.02	4.76	7.89	0.53
0.47	5.18	85.7	74.0	79.8	19.8	10.84	4.81	7.83	0.52
0.48	5.29	85.7	74.0	79.8	19.9	10.68	4.86	7.77	0.51
0.49	5.40	85.7	74.0	79.8	20.0	10.53	4.91	7.72	0.50
0.50	5.51	85.7	74.0	79.8	20.2	10.38	4.96	7.67	0.50
0.51	5.62	85.7	74.0	79.9	20.3	10.26	5.01	7.63	0.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	5.73	85.8	74.0	79.9	20.4	10.15	5.05	7.60	0.50
0.53	5.84	85.8	74.0	79.9	20.6	10.05	5.09	7.57	0.50
0.54	5.95	85.8	74.0	79.9	20.7	9.98	5.13	7.55	0.50
0.55	6.06	85.8	74.0	79.9	20.8	9.91	5.16	7.53	0.50
0.56	6.18	85.8	74.0	79.9	21.0	9.85	5.19	7.52	0.50
0.57	6.29	85.8	74.0	79.9	21.1	9.81	5.22	7.51	0.50
0.58	6.40	85.8	74.0	79.9	21.2	9.77	5.25	7.51	0.50
0.59	6.51	85.8	74.0	79.9	21.4	9.74	5.27	7.50	0.50
0.60	6.62	85.8	74.0	79.9	21.5	9.71	5.29	7.50	0.50
0.61	6.74	85.9	74.0	79.9	21.6	9.69	5.32	7.50	0.50
0.62	6.85	85.9	74.0	79.9	21.8	9.67	5.34	7.50	0.50
0.63	6.96	85.9	74.0	79.9	21.9	9.65	5.36	7.50	0.50
0.64	7.08	85.9	74.0	79.9	22.0	9.64	5.37	7.51	0.50
0.65	7.19	85.9	74.0	79.9	22.2	9.63	5.39	7.51	0.50
0.66	7.30	85.9	74.0	79.9	22.3	9.62	5.41	7.51	0.50
0.67	7.42	85.9	74.0	79.9	22.5	9.61	5.42	7.52	0.50
0.68	7.53	85.9	74.0	79.9	22.6	9.61	5.43	7.52	0.50
0.69	7.65	85.9	74.0	79.9	22.7	9.60	5.45	7.53	0.50
0.70	7.76	85.9	74.0	80.0	22.9	9.60	5.46	7.53	0.50
0.71	7.88	85.9	74.0	80.0	23.0	9.60	5.47	7.53	0.50
0.72	7.99	85.9	74.0	80.0	23.1	9.60	5.48	7.54	0.50
0.73	8.11	85.9	74.0	80.0	23.3	9.60	5.49	7.54	0.50
0.74	8.22	85.9	74.0	80.0	23.4	9.59	5.50	7.55	0.50
0.75	8.34	85.9	74.0	80.0	23.6	9.59	5.51	7.55	0.50
0.76	8.46	85.9	74.0	80.0	23.7	9.59	5.52	7.56	0.50
0.77	8.57	85.9	74.0	80.0	23.8	9.59	5.53	7.56	0.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	8.69	85.9	74.0	80.0	24.0	9.59	5.54	7.57	0.50
0.79	8.81	85.9	74.0	80.0	24.1	9.60	5.54	7.57	0.50
0.80	8.92	86.0	74.0	80.0	24.3	9.60	5.55	7.57	0.50
0.81	9.04	86.0	74.0	80.0	24.4	9.60	5.56	7.58	0.50
0.82	9.16	86.0	74.0	80.0	24.5	9.60	5.56	7.58	0.50
0.83	9.28	86.0	74.0	80.0	24.7	9.60	5.57	7.58	0.50
0.84	9.40	86.0	74.0	80.0	24.8	9.60	5.57	7.59	0.50
0.85	9.52	86.0	74.0	80.0	25.0	9.60	5.58	7.59	0.50
0.86	9.63	86.0	74.0	80.0	25.1	9.60	5.58	7.59	0.50
0.87	9.75	86.0	74.0	80.0	25.3	9.60	5.59	7.60	0.50
0.88	9.87	86.0	74.0	80.0	25.4	9.60	5.59	7.60	0.50
0.89	9.99	86.0	74.0	80.0	25.5	9.61	5.60	7.60	0.50
0.90	10.11	86.0	74.0	80.0	25.7	9.61	5.60	7.60	0.50
0.91	10.23	86.0	74.0	80.0	25.8	9.61	5.61	7.61	0.50
0.92	10.35	86.0	74.0	80.0	26.0	9.61	5.61	7.61	0.50
0.93	10.47	86.0	74.0	80.0	26.1	9.61	5.61	7.61	0.50
0.94	10.60	86.0	74.0	80.0	26.3	9.61	5.62	7.61	0.50
0.95	10.72	86.0	74.0	80.0	26.4	9.61	5.62	7.62	0.50
0.96	10.84	86.0	74.0	80.0	26.6	9.61	5.62	7.62	0.50
0.97	10.96	86.0	74.0	80.0	26.7	9.61	5.62	7.62	0.50
0.98	11.08	86.0	74.0	80.0	26.9	9.62	5.63	7.62	0.50
0.99	11.20	86.0	74.0	80.0	27.0	9.62	5.63	7.62	0.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	1.00	2.44	3.45	0.68	4.13	0.30	0.40	0.10
0.0	0.37	2.80	2.95	5.74	7.72	13.46	1.71	10.55	34.35
0.01	0.47	2.68	2.93	5.60	7.26	12.86	1.76	10.31	31.53
0.02	0.56	2.55	2.89	5.43	6.83	12.26	1.81	10.08	28.95
0.03	0.66	2.42	2.85	5.27	6.43	11.70	1.85	9.85	26.57
0.04	0.76	2.31	2.81	5.12	6.04	11.16	1.88	9.62	24.38
0.05	0.85	2.20	2.78	4.98	5.68	10.66	1.90	9.41	22.36
0.06	0.95	2.09	2.75	4.84	5.34	10.18	1.91	9.19	20.51
0.07	1.05	2.00	2.72	4.71	5.02	9.74	1.91	8.99	18.81
0.08	1.15	1.90	2.69	4.59	4.72	9.31	1.91	8.78	17.25
0.09	1.24	1.81	2.66	4.48	4.44	8.92	1.90	8.58	15.82
0.10	1.34	1.73	2.64	4.37	4.17	8.54	1.89	8.39	14.50
0.11	1.44	1.65	2.62	4.27	3.92	8.19	1.87	8.20	13.30
0.12	1.54	1.58	2.60	4.17	3.69	7.86	1.85	8.01	12.19
0.13	1.64	1.50	2.58	4.08	3.47	7.55	1.82	7.83	11.18
0.14	1.74	1.44	2.56	4.00	3.26	7.25	1.80	7.66	10.25
0.15	1.84	1.37	2.54	3.92	3.06	6.98	1.76	7.48	9.40
0.16	1.94	1.31	2.53	3.84	2.88	6.72	1.73	7.31	8.61
0.17	2.04	1.25	2.51	3.77	2.71	6.48	1.70	7.15	7.90
0.18	2.14	1.20	2.50	3.70	2.55	6.25	1.66	6.99	7.24
0.19	2.24	1.15	2.49	3.63	2.40	6.03	1.62	6.83	6.64
0.20	2.34	1.10	2.47	3.57	2.26	5.83	1.59	6.68	6.09
0.21	2.44	1.05	2.46	3.51	2.12	5.64	1.55	6.53	5.58
0.22	2.55	1.00	2.45	3.46	2.00	5.46	1.51	6.38	5.12
0.23	2.65	0.96	2.44	3.41	1.88	5.29	1.47	6.24	4.70
0.24	2.75	0.92	2.44	3.36	1.77	5.13	1.43	6.10	4.31
0.25	2.85	0.88	2.43	3.31	1.67	4.98	1.39	5.96	3.95

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.96	0.85	2.42	3.26	1.57	4.84	1.35	5.83	3.63
0.27	3.06	0.81	2.41	3.22	1.48	4.71	1.31	5.70	3.33
0.28	3.16	0.78	2.41	3.18	1.40	4.58	1.27	5.57	3.06
0.29	3.27	0.74	2.40	3.15	1.32	4.46	1.23	5.45	2.80
0.30	3.37	0.71	2.40	3.11	1.24	4.35	1.19	5.33	2.58
0.31	3.48	0.68	2.39	3.08	1.17	4.25	1.15	5.21	2.36
0.32	3.58	0.66	2.39	3.04	1.11	4.15	1.11	5.09	2.17
0.33	3.69	0.63	2.38	3.01	1.05	4.06	1.08	4.98	1.99
0.34	3.79	0.60	2.38	2.98	0.99	3.97	1.04	4.87	1.83
0.35	3.90	0.58	2.38	2.96	0.94	3.89	1.01	4.76	1.68
0.36	4.00	0.56	2.37	2.93	0.88	3.81	0.98	4.66	1.55
0.37	4.11	0.53	2.37	2.91	0.84	3.74	0.95	4.56	1.42
0.38	4.21	0.51	2.37	2.88	0.79	3.67	0.92	4.46	1.31
0.39	4.32	0.49	2.37	2.86	0.75	3.61	0.89	4.36	1.20
0.40	4.43	0.47	2.36	2.84	0.71	3.55	0.86	4.26	1.11
0.41	4.54	0.46	2.36	2.82	0.67	3.49	0.83	4.17	1.02
0.42	4.64	0.44	2.36	2.80	0.64	3.44	0.81	4.08	0.94
0.43	4.75	0.42	2.36	2.78	0.61	3.38	0.78	3.99	0.86
0.44	4.86	0.40	2.36	2.76	0.58	3.34	0.76	3.90	0.79
0.45	4.97	0.39	2.36	2.74	0.55	3.29	0.74	3.82	0.73
0.46	5.08	0.37	2.36	2.73	0.52	3.25	0.72	3.74	0.67
0.47	5.18	0.36	2.35	2.71	0.49	3.21	0.70	3.66	0.62
0.48	5.29	0.34	2.35	2.70	0.47	3.17	0.68	3.58	0.57
0.49	5.40	0.33	2.35	2.68	0.45	3.13	0.66	3.50	0.52
0.50	5.51	0.32	2.35	2.67	0.43	3.10	0.64	3.43	0.48
0.51	5.62	0.31	2.35	2.66	0.41	3.06	0.62	3.35	0.45

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	5.73	0.30	2.35	2.65	0.39	3.03	0.60	3.28	0.41
0.53	5.84	0.28	2.35	2.64	0.37	3.00	0.59	3.21	0.38
0.54	5.95	0.27	2.35	2.62	0.35	2.98	0.57	3.14	0.35
0.55	6.06	0.26	2.35	2.61	0.34	2.95	0.56	3.08	0.32
0.56	6.18	0.25	2.35	2.60	0.32	2.92	0.55	3.01	0.30
0.57	6.29	0.24	2.35	2.59	0.31	2.90	0.53	2.95	0.28
0.58	6.40	0.23	2.35	2.58	0.29	2.88	0.52	2.89	0.25
0.59	6.51	0.23	2.35	2.58	0.28	2.86	0.51	2.82	0.24
0.60	6.62	0.22	2.35	2.57	0.27	2.84	0.50	2.77	0.23
0.61	6.74	0.21	2.35	2.56	0.26	2.82	0.49	2.71	0.21
0.62	6.85	0.20	2.35	2.55	0.25	2.80	0.48	2.65	0.20
0.63	6.96	0.19	2.35	2.54	0.24	2.78	0.47	2.60	0.19
0.64	7.08	0.19	2.35	2.54	0.23	2.77	0.46	2.54	0.18
0.65	7.19	0.18	2.35	2.53	0.22	2.75	0.46	2.49	0.17
0.66	7.30	0.17	2.35	2.52	0.21	2.73	0.45	2.44	0.16
0.67	7.42	0.17	2.35	2.52	0.20	2.72	0.44	2.39	0.15
0.68	7.53	0.16	2.35	2.51	0.20	2.71	0.43	2.34	0.15
0.69	7.65	0.15	2.35	2.50	0.19	2.69	0.43	2.29	0.14
0.70	7.76	0.15	2.35	2.50	0.18	2.68	0.42	2.24	0.13
0.71	7.88	0.14	2.35	2.49	0.18	2.67	0.41	2.20	0.13
0.72	7.99	0.14	2.35	2.49	0.17	2.66	0.41	2.15	0.12
0.73	8.11	0.13	2.35	2.48	0.16	2.65	0.40	2.11	0.12
0.74	8.22	0.13	2.35	2.48	0.16	2.64	0.40	2.06	0.11
0.75	8.34	0.12	2.35	2.47	0.15	2.63	0.39	2.02	0.11
0.76	8.46	0.12	2.35	2.47	0.15	2.62	0.39	1.98	0.10
0.77	8.57	0.12	2.35	2.46	0.15	2.61	0.39	1.94	0.10

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

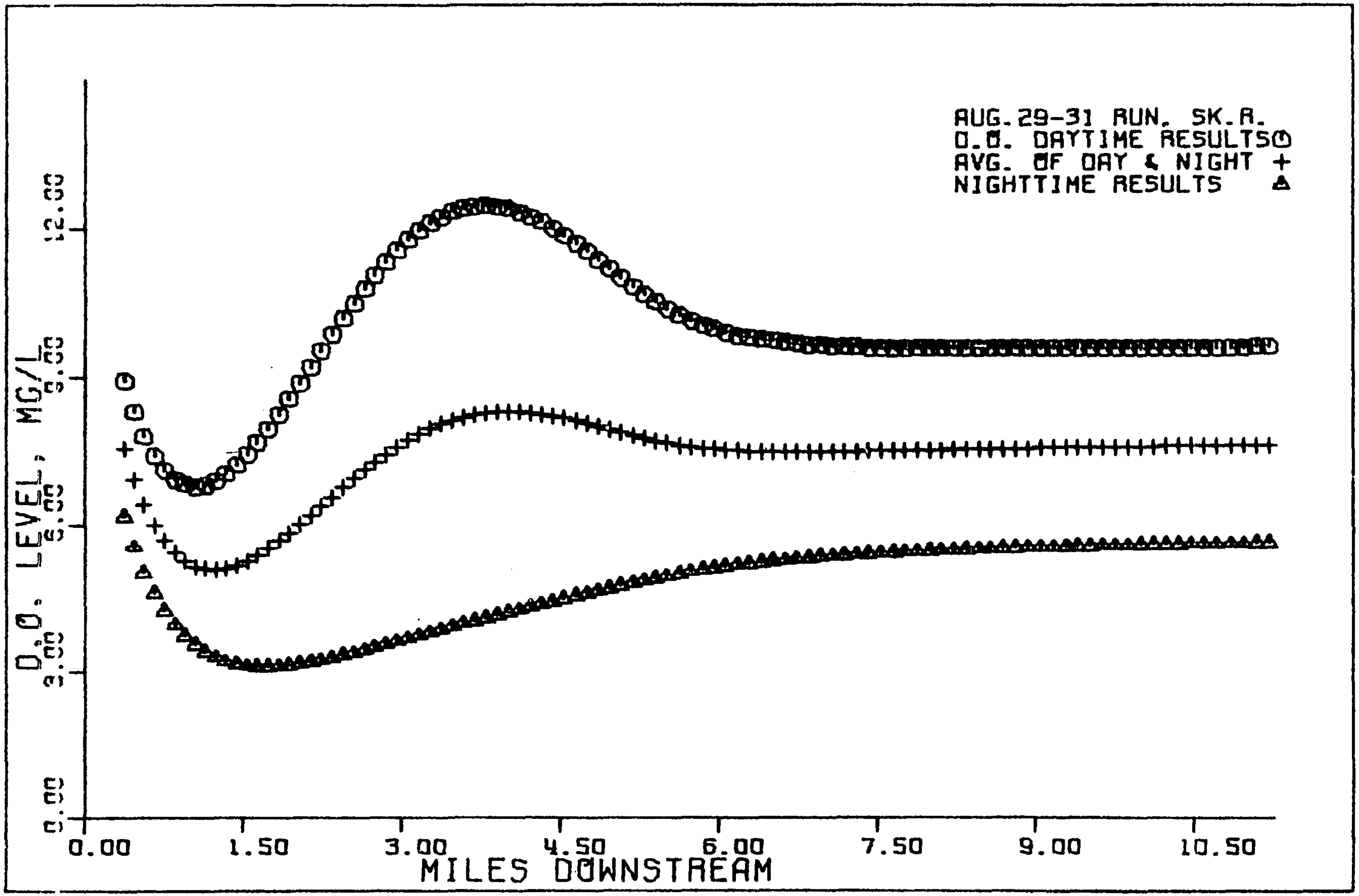
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	8.69	0.11	2.35	2.46	0.14	2.60	0.38	1.90	0.10
0.79	8.81	0.11	2.35	2.46	0.14	2.59	0.38	1.86	0.10
0.80	8.92	0.10	2.35	2.45	0.13	2.58	0.37	1.83	0.10
0.81	9.04	0.10	2.35	2.45	0.13	2.58	0.37	1.79	0.10
0.82	9.16	0.10	2.35	2.44	0.13	2.57	0.37	1.75	0.10
0.83	9.28	0.09	2.35	2.44	0.12	2.56	0.36	1.72	0.10
0.84	9.40	0.09	2.35	2.44	0.12	2.56	0.36	1.68	0.10
0.85	9.52	0.09	2.35	2.43	0.12	2.55	0.36	1.65	0.10
0.86	9.63	0.08	2.35	2.43	0.11	2.54	0.36	1.62	0.10
0.87	9.75	0.08	2.35	2.43	0.11	2.54	0.35	1.59	0.10
0.88	9.87	0.08	2.35	2.42	0.11	2.53	0.35	1.55	0.10
0.89	9.99	0.07	2.35	2.42	0.11	2.53	0.35	1.52	0.10
0.90	10.11	0.07	2.35	2.42	0.10	2.52	0.35	1.49	0.10
0.91	10.23	0.07	2.35	2.42	0.10	2.52	0.34	1.46	0.10
0.92	10.35	0.07	2.35	2.41	0.10	2.51	0.34	1.44	0.10
0.93	10.47	0.06	2.35	2.41	0.10	2.51	0.34	1.41	0.10
0.94	10.60	0.06	2.35	2.41	0.10	2.50	0.34	1.38	0.10
0.95	10.72	0.06	2.35	2.41	0.09	2.50	0.34	1.35	0.10
0.96	10.84	0.06	2.35	2.40	0.09	2.50	0.33	1.33	0.10
0.97	10.96	0.06	2.35	2.40	0.09	2.49	0.33	1.30	0.10
0.98	11.08	0.05	2.35	2.40	0.09	2.49	0.33	1.28	0.10
0.99	11.20	0.05	2.34	2.40	0.09	2.48	0.33	1.25	0.10

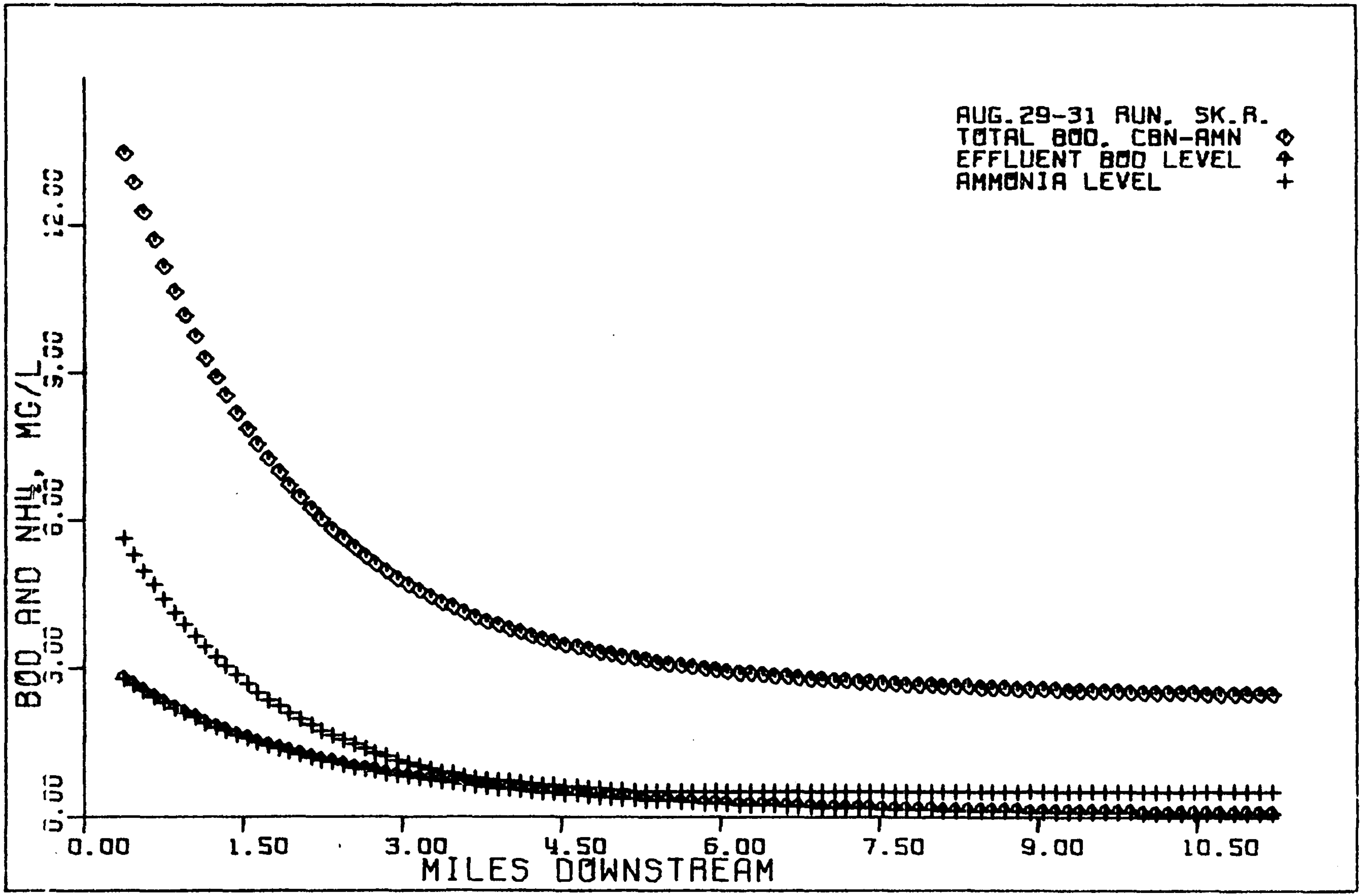
WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD AND OTHER DATA FOR AUG. 29-31, 1966, COMPLETE TREATMENT
SEASON : SUMMER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.93	0.37	0.0	6.17	0.37	0.0
MINIMUM DO, MG/L	6.79	1.05	0.07	3.11	1.74	0.14
FINAL DO, MG/L	9.60	8.92	0.80	5.55	8.92	0.80
DO DEFICIT						
INITIAL, MG/L	-1.35	0.37	0.0	2.08	0.37	0.0
FINAL, MG/L	-2.38	8.92	0.80	2.64	8.92	0.80
RIVER DISCHARGE						
INITIAL, CFS	14.00	0.37	0.0	14.00	0.37	0.0
FINAL, CFS	24.26	8.92	0.80	24.26	8.92	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	81.20	0.37	0.0	73.31	0.37	0.0
FINAL, DEG F	85.95	8.92	0.80	73.99	8.92	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	2.80	0.37	0.0	2.80	0.37	0.0
FINAL BOD, MG/L	0.07	8.92	0.80	0.13	8.92	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.08	0.37	0.0	0.08	0.37	0.0
FINAL BOD IN RIVER	2.11	8.92	0.80	2.59	8.92	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	7.72	0.37	0.0	7.72	0.37	0.0
FINAL BOD, MG/L	0.06	8.92	0.80	0.20	8.92	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	12.96	0.37	0.0	13.96	0.37	0.0
FINAL VALUE, MG/L	2.24	8.92	0.80	2.93	8.92	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	5.64	0.37	0.0	5.64	0.37	0.0
FINAL VALUE, MG/L	0.50	8.92	0.80	0.50	8.92	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	1.71	0.37	0.0	1.71	0.37	0.0
FINAL VALUE, MG/L	0.36	8.92	0.80	0.39	8.92	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	10.55	0.37	0.0	10.55	0.37	0.0
FINAL VALUE, MG/L	1.49	8.92	0.80	2.16	8.92	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	34.35	0.37	0.0	34.35	0.37	0.0
FINAL PERCENT	0.10	8.92	0.80	0.10	8.92	0.80


AUG.29-31 RUN. SK.R.
D.O. DAYTIME RESULTS ⊙
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM


AUG.29-31 RUN. SK.R.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM

E. Simulation Results for September 7-17, 1966

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
2.90	72.00	75.00	0.0	4.00	0.080	0.0	14.00	4.00	12.00	100.00	0.0	0.0	0.80	0.35

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
71.00	53.00	120.00	60.00	1.00	0.140	0.0	1.50	1.10	1.10	0.10	50.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDP
2.20	0.90	80.00	50.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.200	2.500	1.300	0.960

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
71.00	53.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.50	3.20	3.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
     RUN IDENT : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
     SEASON : FALL

 GAMMA1 =   0.80 , GAMMA2 =   0.35
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   3.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   4.49 CFS, RIVER Q =   2.20 CFS, TOTAL Q =   6.69 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	71.0	53.0		2.2	10.15	6.30		1.50
0.0	0.37	71.7	65.8	68.7	6.7	7.55	6.29	6.92	9.89
0.01	0.44	71.6	65.0	68.3	6.8	6.99	5.53	6.26	9.50
0.02	0.52	71.6	64.4	68.0	6.8	6.53	4.89	5.71	9.14
0.03	0.59	71.6	63.7	67.6	6.9	6.17	4.36	5.26	8.79
0.04	0.66	71.5	63.1	67.3	7.0	5.88	3.94	4.91	8.46
0.05	0.74	71.5	62.6	67.0	7.0	5.67	3.59	4.63	8.15
0.06	0.81	71.5	62.0	66.8	7.1	5.52	3.32	4.42	7.85
0.07	0.88	71.4	61.5	66.5	7.2	5.42	3.11	4.26	7.57
0.08	0.96	71.4	61.0	66.2	7.2	5.36	2.95	4.16	7.30
0.09	1.03	71.4	60.6	66.0	7.3	5.35	2.83	4.09	7.04
0.10	1.11	71.4	60.2	65.8	7.4	5.37	2.75	4.06	6.80
0.11	1.18	71.4	59.8	65.6	7.4	5.42	2.70	4.06	6.56
0.12	1.26	71.3	59.4	65.4	7.5	5.49	2.68	4.08	6.34
0.13	1.34	71.3	59.0	65.2	7.6	5.59	2.67	4.13	6.12
0.14	1.41	71.3	58.7	65.0	7.6	5.70	2.69	4.20	5.92
0.15	1.49	71.3	58.4	64.8	7.7	5.83	2.72	4.28	5.72
0.16	1.57	71.3	58.1	64.7	7.8	5.98	2.77	4.37	5.54
0.17	1.64	71.3	57.8	64.5	7.8	6.14	2.82	4.48	5.36
0.18	1.72	71.2	57.5	64.4	7.9	6.31	2.88	4.60	5.18
0.19	1.80	71.2	57.3	64.3	8.0	6.49	2.95	4.72	5.02
0.20	1.87	71.2	57.0	64.1	8.0	6.67	3.03	4.85	4.86
0.21	1.95	71.2	56.8	64.0	8.1	6.86	3.11	4.98	4.71
0.22	2.03	71.2	56.6	63.9	8.2	7.06	3.19	5.12	4.56
0.23	2.11	71.2	56.4	63.8	8.3	7.26	3.27	5.27	4.42
0.24	2.19	71.2	56.2	63.7	8.3	7.47	3.35	5.41	4.29
0.25	2.27	71.2	56.0	63.6	8.4	7.67	3.44	5.56	4.16

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.35	71.2	55.9	63.5	8.5	7.88	3.52	5.70	4.03
0.27	2.43	71.1	55.7	63.4	8.5	8.09	3.61	5.85	3.91
0.28	2.51	71.1	55.5	63.3	8.6	8.30	3.69	6.00	3.80
0.29	2.59	71.1	55.4	63.3	8.7	8.51	3.78	6.14	3.69
0.30	2.67	71.1	55.3	63.2	8.8	8.72	3.86	6.29	3.58
0.31	2.75	71.1	55.1	63.1	8.8	8.93	3.94	6.43	3.48
0.32	2.83	71.1	55.0	63.1	8.9	9.13	4.01	6.57	3.38
0.33	2.91	71.1	54.9	63.0	9.0	9.34	4.09	6.71	3.29
0.34	2.99	71.1	54.8	63.0	9.0	9.54	4.17	6.85	3.19
0.35	3.07	71.1	54.7	62.9	9.1	9.74	4.24	6.99	3.10
0.36	3.15	71.1	54.6	62.8	9.2	9.93	4.31	7.12	3.02
0.37	3.23	71.1	54.5	62.8	9.3	10.12	4.38	7.25	2.94
0.38	3.32	71.1	54.4	62.8	9.3	10.31	4.44	7.37	2.86
0.39	3.40	71.1	54.4	62.7	9.4	10.49	4.51	7.50	2.78
0.40	3.48	71.1	54.3	62.7	9.5	10.66	4.57	7.62	2.71
0.41	3.56	71.1	54.2	62.6	9.6	10.83	4.63	7.73	2.64
0.42	3.65	71.1	54.1	62.6	9.6	11.00	4.69	7.84	2.57
0.43	3.73	71.1	54.1	62.6	9.7	11.15	4.74	7.95	2.50
0.44	3.81	71.1	54.0	62.5	9.8	11.30	4.80	8.05	2.44
0.45	3.90	71.1	54.0	62.5	9.9	11.45	4.85	8.15	2.38
0.46	3.98	71.0	53.9	62.5	9.9	11.59	4.90	8.24	2.32
0.47	4.07	71.0	53.9	62.4	10.0	11.72	4.95	8.33	2.26
0.48	4.15	71.0	53.8	62.4	10.1	11.84	5.00	8.42	2.21
0.49	4.24	71.0	53.8	62.4	10.2	11.95	5.04	8.50	2.18
0.50	4.32	71.0	53.7	62.4	10.2	12.06	5.08	8.57	2.16
0.51	4.41	71.0	53.7	62.4	10.3	12.16	5.13	8.64	2.13

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.49	71.0	53.6	62.3	10.4	12.25	5.17	8.71	2.10
0.53	4.58	71.0	53.6	62.3	10.5	12.33	5.21	8.77	2.07
0.54	4.66	71.0	53.6	62.3	10.6	12.40	5.24	8.82	2.05
0.55	4.75	71.0	53.5	62.3	10.6	12.47	5.28	8.87	2.02
0.56	4.84	71.0	53.5	62.3	10.7	12.52	5.31	8.92	2.00
0.57	4.92	71.0	53.5	62.3	10.8	12.57	5.35	8.96	1.98
0.58	5.01	71.0	53.5	62.2	10.9	12.61	5.38	8.99	1.95
0.59	5.10	71.0	53.4	62.2	10.9	12.64	5.41	9.02	1.93
0.60	5.18	71.0	53.4	62.2	11.0	12.66	5.44	9.05	1.91
0.61	5.27	71.0	53.4	62.2	11.1	12.67	5.46	9.07	1.89
0.62	5.36	71.0	53.4	62.2	11.2	12.68	5.49	9.09	1.87
0.63	5.45	71.0	53.3	62.2	11.3	12.68	5.52	9.10	1.85
0.64	5.54	71.0	53.3	62.2	11.3	12.67	5.54	9.10	1.83
0.65	5.63	71.0	53.3	62.2	11.4	12.65	5.56	9.11	1.81
0.66	5.71	71.0	53.3	62.2	11.5	12.62	5.58	9.10	1.79
0.67	5.80	71.0	53.3	62.1	11.6	12.59	5.61	9.10	1.77
0.68	5.89	71.0	53.3	62.1	11.7	12.55	5.62	9.09	1.75
0.69	5.98	71.0	53.2	62.1	11.7	12.50	5.64	9.07	1.73
0.70	6.07	71.0	53.2	62.1	11.8	12.45	5.66	9.05	1.72
0.71	6.16	71.0	53.2	62.1	11.9	12.39	5.68	9.03	1.70
0.72	6.25	71.0	53.2	62.1	12.0	12.32	5.69	9.01	1.68
0.73	6.34	71.0	53.2	62.1	12.1	12.25	5.71	8.98	1.67
0.74	6.43	71.0	53.2	62.1	12.1	12.17	5.72	8.95	1.65
0.75	6.52	71.0	53.2	62.1	12.2	12.09	5.73	8.91	1.64
0.76	6.62	71.0	53.2	62.1	12.3	12.01	5.74	8.87	1.62
0.77	6.71	71.0	53.2	62.1	12.4	11.92	5.75	8.84	1.61

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	6.80	71.0	53.1	62.1	12.5	11.83	5.76	8.79	1.59
0.79	6.89	71.0	53.1	62.1	12.6	11.73	5.77	8.75	1.58
0.80	6.98	71.0	53.1	62.1	12.6	11.64	5.77	8.70	1.57
0.81	7.07	71.0	53.1	62.1	12.7	11.54	5.78	8.66	1.55
0.82	7.17	71.0	53.1	62.1	12.8	11.44	5.78	8.61	1.54
0.83	7.26	71.0	53.1	62.1	12.9	11.34	5.78	8.56	1.53
0.84	7.35	71.0	53.1	62.1	13.0	11.23	5.78	8.51	1.52
0.85	7.45	71.0	53.1	62.1	13.1	11.13	5.78	8.45	1.50
0.86	7.54	71.0	53.1	62.0	13.1	11.03	5.78	8.40	1.50
0.87	7.63	71.0	53.1	62.0	13.2	10.93	5.77	8.35	1.50
0.88	7.73	71.0	53.1	62.0	13.3	10.83	5.76	8.30	1.50
0.89	7.82	71.0	53.1	62.0	13.4	10.73	5.76	8.24	1.50
0.90	7.92	71.0	53.1	62.0	13.5	10.64	5.75	8.19	1.50
0.91	8.01	71.0	53.1	62.0	13.6	10.54	5.74	8.14	1.50
0.92	8.10	71.0	53.1	62.0	13.7	10.45	5.72	8.09	1.50
0.93	8.20	71.0	53.1	62.0	13.7	10.37	5.71	8.04	1.50
0.94	8.29	71.0	53.1	62.0	13.8	10.28	5.70	7.99	1.50
0.95	8.39	71.0	53.1	62.0	13.9	10.21	5.68	7.94	1.50
0.96	8.49	71.0	53.1	62.0	14.0	10.13	5.66	7.90	1.50
0.97	8.58	71.0	53.0	62.0	14.1	10.06	5.65	7.86	1.50
0.98	8.68	71.0	53.0	62.0	14.2	10.00	5.63	7.82	1.50
0.99	8.77	71.0	53.0	62.0	14.3	9.94	5.62	7.78	1.50

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	1.00	4.62	5.62	1.20	6.81	1.10	1.10	0.10
0.0	0.37	3.90	5.22	9.12	7.89	17.01	3.05	8.42	67.14
0.01	0.44	3.78	5.19	8.97	7.58	16.56	3.00	8.30	62.58
0.02	0.52	3.66	5.15	8.81	7.29	16.10	2.95	8.20	58.37
0.03	0.59	3.55	5.11	8.65	7.02	15.67	2.90	8.09	54.48
0.04	0.66	3.43	5.07	8.51	6.75	15.26	2.85	7.99	50.88
0.05	0.74	3.33	5.04	8.37	6.50	14.87	2.80	7.89	47.54
0.06	0.81	3.23	5.01	8.23	6.27	14.50	2.74	7.79	44.44
0.07	0.88	3.13	4.98	8.10	6.04	14.14	2.69	7.69	41.57
0.08	0.96	3.03	4.95	7.98	5.83	13.81	2.63	7.60	38.91
0.09	1.03	2.94	4.92	7.87	5.62	13.49	2.57	7.50	36.43
0.10	1.11	2.86	4.90	7.76	5.42	13.18	2.52	7.41	34.13
0.11	1.18	2.77	4.88	7.65	5.24	12.89	2.46	7.32	31.98
0.12	1.26	2.69	4.86	7.55	5.06	12.61	2.40	7.23	29.99
0.13	1.34	2.62	4.84	7.45	4.89	12.34	2.35	7.15	28.13
0.14	1.41	2.54	4.82	7.36	4.72	12.08	2.29	7.06	26.39
0.15	1.49	2.47	4.80	7.27	4.57	11.84	2.24	6.98	24.78
0.16	1.57	2.40	4.79	7.19	4.42	11.60	2.19	6.90	23.27
0.17	1.64	2.33	4.77	7.11	4.27	11.38	2.13	6.82	21.86
0.18	1.72	2.27	4.76	7.03	4.14	11.16	2.08	6.74	20.54
0.19	1.80	2.21	4.75	6.95	4.00	10.96	2.03	6.66	19.31
0.20	1.87	2.15	4.74	6.88	3.88	10.76	1.98	6.58	18.16
0.21	1.95	2.09	4.73	6.81	3.76	10.57	1.93	6.51	17.09
0.22	2.03	2.03	4.72	6.75	3.64	10.39	1.88	6.43	16.08
0.23	2.11	1.98	4.71	6.69	3.53	10.21	1.84	6.36	15.14
0.24	2.19	1.92	4.70	6.62	3.42	10.05	1.79	6.29	14.25
0.25	2.27	1.87	4.69	6.57	3.32	9.88	1.74	6.22	13.43

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.35	1.82	4.69	6.51	3.22	9.73	1.70	6.15	12.65
0.27	2.43	1.78	4.68	6.46	3.12	9.58	1.66	6.09	11.92
0.28	2.51	1.73	4.68	6.41	3.03	9.44	1.62	6.02	11.24
0.29	2.59	1.69	4.67	6.36	2.94	9.30	1.58	5.95	10.60
0.30	2.67	1.64	4.67	6.31	2.86	9.17	1.54	5.89	10.00
0.31	2.75	1.60	4.66	6.26	2.78	9.04	1.50	5.83	9.44
0.32	2.83	1.56	4.66	6.22	2.70	8.92	1.46	5.76	8.91
0.33	2.91	1.52	4.66	6.18	2.62	8.80	1.42	5.70	8.41
0.34	2.99	1.48	4.66	6.14	2.55	8.68	1.39	5.64	7.94
0.35	3.07	1.44	4.65	6.10	2.48	8.58	1.35	5.58	7.50
0.36	3.15	1.41	4.65	6.06	2.41	8.47	1.32	5.52	7.09
0.37	3.23	1.37	4.65	6.02	2.34	8.37	1.29	5.47	6.70
0.38	3.32	1.34	4.65	5.99	2.28	8.27	1.26	5.41	6.33
0.39	3.40	1.31	4.65	5.96	2.22	8.18	1.23	5.35	5.98
0.40	3.48	1.27	4.65	5.92	2.16	8.08	1.22	5.30	5.66
0.41	3.56	1.24	4.65	5.89	2.10	8.00	1.21	5.24	5.35
0.42	3.65	1.21	4.65	5.86	2.05	7.91	1.19	5.19	5.06
0.43	3.73	1.18	4.65	5.83	2.00	7.83	1.18	5.14	4.79
0.44	3.81	1.15	4.65	5.80	1.95	7.75	1.17	5.09	4.54
0.45	3.90	1.13	4.65	5.78	1.90	7.67	1.16	5.04	4.30
0.46	3.98	1.10	4.65	5.75	1.85	7.60	1.15	4.99	4.07
0.47	4.07	1.07	4.65	5.73	1.80	7.53	1.13	4.94	3.85
0.48	4.15	1.05	4.66	5.70	1.76	7.46	1.12	4.89	3.65
0.49	4.24	1.02	4.66	5.68	1.71	7.40	1.11	4.84	3.46
0.50	4.32	1.00	4.66	5.66	1.67	7.33	1.10	4.79	3.28
0.51	4.41	0.97	4.66	5.64	1.63	7.27	1.10	4.75	3.11

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.49	0.95	4.66	5.62	1.59	7.21	1.10	4.70	2.95
0.53	4.58	0.93	4.67	5.60	1.56	7.15	1.10	4.65	2.79
0.54	4.66	0.91	4.67	5.58	1.52	7.10	1.10	4.61	2.65
0.55	4.75	0.89	4.67	5.56	1.48	7.04	1.10	4.57	2.51
0.56	4.84	0.87	4.67	5.54	1.45	6.99	1.10	4.52	2.38
0.57	4.92	0.85	4.68	5.52	1.42	6.94	1.10	4.48	2.26
0.58	5.01	0.83	4.68	5.51	1.39	6.89	1.10	4.44	2.15
0.59	5.10	0.81	4.68	5.49	1.35	6.85	1.10	4.40	2.04
0.60	5.18	0.79	4.69	5.48	1.32	6.80	1.10	4.36	1.94
0.61	5.27	0.77	4.69	5.46	1.30	6.76	1.10	4.31	1.84
0.62	5.36	0.75	4.69	5.45	1.27	6.71	1.10	4.28	1.75
0.63	5.45	0.74	4.70	5.43	1.24	6.67	1.10	4.24	1.66
0.64	5.54	0.72	4.70	5.42	1.21	6.63	1.10	4.20	1.58
0.65	5.63	0.70	4.70	5.41	1.19	6.60	1.10	4.16	1.50
0.66	5.71	0.69	4.71	5.40	1.16	6.56	1.10	4.12	1.42
0.67	5.80	0.67	4.71	5.38	1.14	6.52	1.10	4.08	1.35
0.68	5.89	0.66	4.72	5.37	1.12	6.49	1.10	4.05	1.29
0.69	5.98	0.64	4.72	5.36	1.09	6.45	1.10	4.01	1.22
0.70	6.07	0.63	4.72	5.35	1.07	6.42	1.10	3.97	1.16
0.71	6.16	0.61	4.73	5.34	1.05	6.39	1.10	3.94	1.11
0.72	6.25	0.60	4.73	5.33	1.03	6.36	1.10	3.90	1.05
0.73	6.34	0.59	4.73	5.32	1.01	6.33	1.10	3.87	1.00
0.74	6.43	0.57	4.74	5.31	0.99	6.30	1.10	3.84	0.95
0.75	6.52	0.56	4.74	5.30	0.97	6.27	1.10	3.80	0.91
0.76	6.62	0.55	4.75	5.30	0.95	6.25	1.10	3.77	0.86
0.77	6.71	0.54	4.75	5.29	0.93	6.22	1.10	3.74	0.82

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

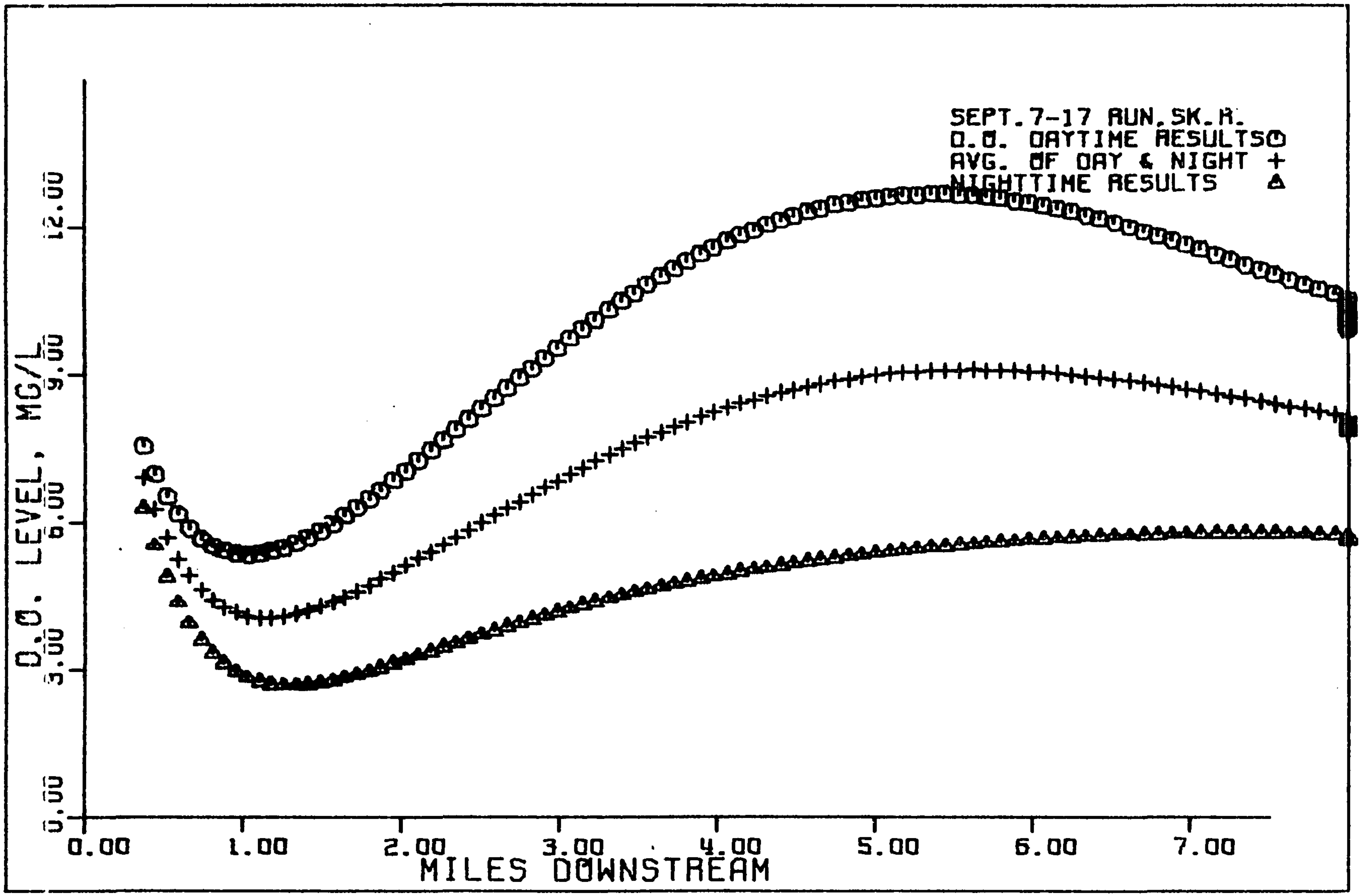
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	6.80	0.53	4.76	5.28	0.92	6.20	1.10	3.71	0.78
0.79	6.89	0.51	4.76	5.27	0.90	6.17	1.10	3.67	0.75
0.80	6.98	0.50	4.76	5.27	0.88	6.15	1.10	3.64	0.71
0.81	7.07	0.49	4.77	5.26	0.87	6.13	1.10	3.61	0.68
0.82	7.17	0.48	4.77	5.25	0.85	6.10	1.10	3.58	0.65
0.83	7.26	0.47	4.78	5.25	0.84	6.08	1.10	3.55	0.61
0.84	7.35	0.46	4.78	5.24	0.82	6.06	1.10	3.52	0.59
0.85	7.45	0.45	4.79	5.24	0.81	6.04	1.10	3.49	0.56
0.86	7.54	0.44	4.79	5.23	0.79	6.02	1.10	3.46	0.53
0.87	7.63	0.43	4.79	5.23	0.78	6.00	1.10	3.43	0.51
0.88	7.73	0.42	4.80	5.22	0.77	5.99	1.10	3.40	0.48
0.89	7.82	0.41	4.80	5.22	0.75	5.97	1.10	3.38	0.46
0.90	7.92	0.40	4.81	5.21	0.74	5.95	1.10	3.35	0.44
0.91	8.01	0.40	4.81	5.21	0.73	5.94	1.10	3.32	0.42
0.92	8.10	0.39	4.82	5.20	0.72	5.92	1.10	3.30	0.40
0.93	8.20	0.38	4.82	5.20	0.71	5.91	1.10	3.27	0.39
0.94	8.29	0.37	4.82	5.20	0.69	5.89	1.10	3.24	0.37
0.95	8.39	0.36	4.83	5.19	0.68	5.88	1.10	3.22	0.36
0.96	8.49	0.36	4.83	5.19	0.67	5.86	1.10	3.19	0.35
0.97	8.58	0.35	4.84	5.19	0.66	5.85	1.10	3.17	0.33
0.98	8.68	0.34	4.84	5.18	0.65	5.84	1.10	3.14	0.32
0.99	8.77	0.33	4.85	5.18	0.64	5.82	1.10	3.12	0.31

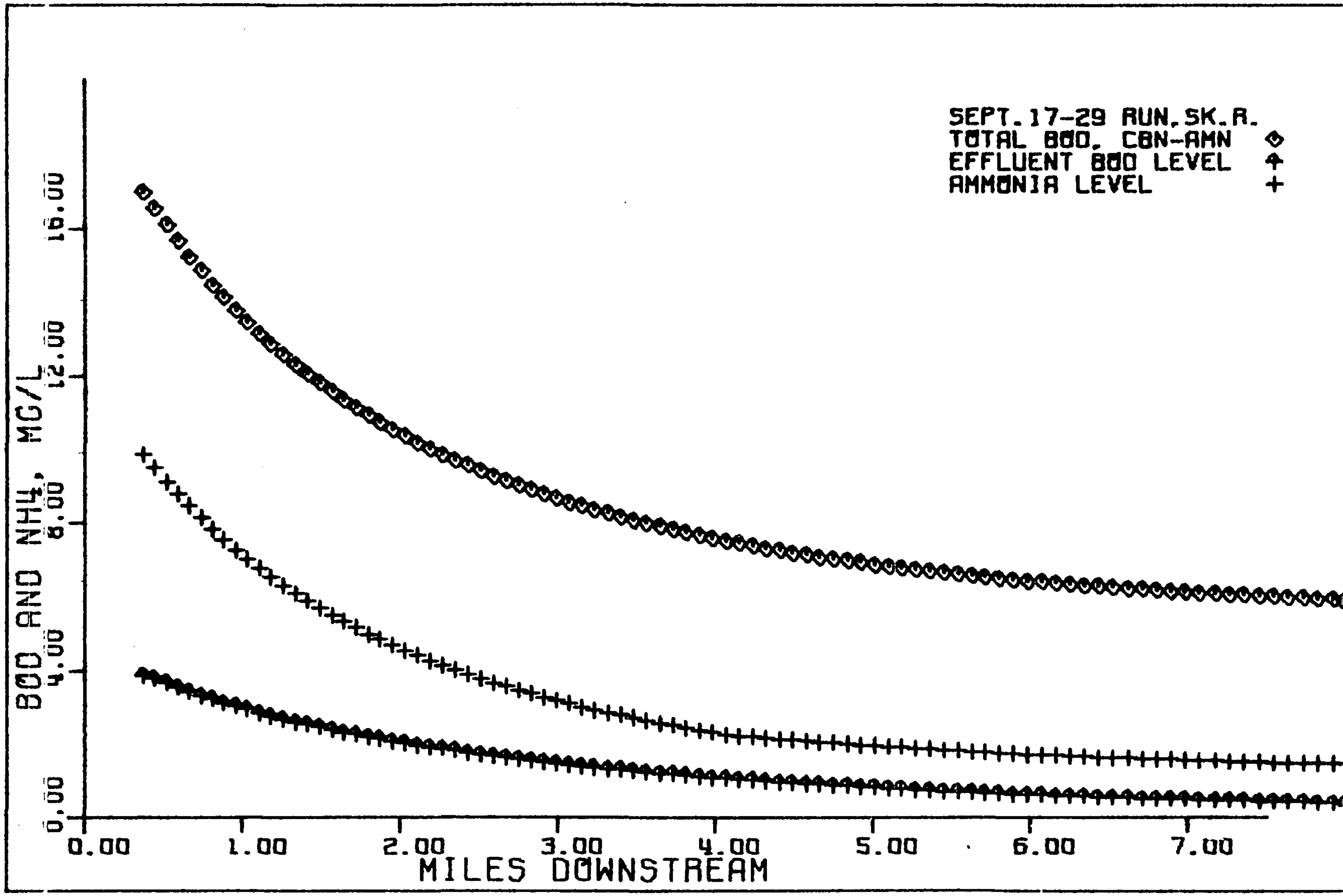
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD AND OTHER DATA FOR SEPT. 7-17, 1966, WITH SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	7.55	C.37	0.0	6.29	0.37	0.0
MINIMUM DO, MG/L	5.35	1.03	0.09	2.67	1.34	0.13
FINAL DC, MG/L	11.64	6.98	0.80	5.77	6.98	0.80
DO DEFICIT						
INITIAL, MG/L	0.85	0.37	0.0	2.69	0.37	0.0
FINAL, MG/L	-3.17	6.98	0.80	4.72	6.98	0.80
RIVER DISCHARGE						
INITIAL, CFS	6.69	0.37	0.0	6.69	0.37	C.0
FINAL, CFS	12.64	6.98	0.80	12.64	6.98	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	71.67	0.37	0.0	65.75	0.37	0.0
FINAL, DEG F	71.01	6.98	0.80	53.13	6.98	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	3.90	0.37	0.0	3.90	0.37	0.0
FINAL BOD, MG/L	0.38	6.98	0.80	0.62	6.98	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.10	0.37	0.0	0.10	0.37	0.0
FINAL BOD IN RIVER	4.18	6.98	0.80	5.35	6.98	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	7.89	0.37	0.0	7.89	0.37	0.0
FINAL BOD, MG/L	0.46	6.98	0.80	1.30	6.98	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	16.41	0.37	0.0	17.62	0.37	0.0
FINAL VALUE, MG/L	5.03	6.98	0.80	7.27	6.98	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	9.89	0.37	0.0	9.89	0.37	0.0
FINAL VALUE, MG/L	1.50	6.98	0.80	1.63	6.98	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.05	0.37	0.0	3.05	0.37	0.0
FINAL VALUE, MG/L	1.10	6.98	0.80	1.10	6.98	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	8.42	0.37	0.0	8.42	0.37	0.0
FINAL VALUE, MG/L	3.41	6.98	0.80	3.87	6.98	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	67.14	0.37	0.0	67.14	0.37	0.0
FINAL PERCENT	0.21	6.98	0.80	1.21	6.98	0.80


SEPT.7-17 RUN.SK.R.
D.O. DAYTIME RESULTS ⊖
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS Δ
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
MILES DOWNSTREAM


SEPT.17-29 RUN.SK.R.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
4.00
8.00
12.00
16.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
MILES DOWNSTREAM

F. Simulation Results for October 6-12, 1966

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.36	69.00	50.00	0.0	28.00	0.080	0.0	19.00	4.70	8.30	100.00	0.0	0.0	0.80	0.35

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
64.00	46.00	125.00	60.00	2.00	0.140	0.0	1.70	2.50	1.80	0.10	50.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.11	0.75	80.00	50.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.200	1.500	2.500	2.100

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
64.00	46.00	2.500	0.0	0.0	2.500	0.100	0.40	1.30	1.60	3.20	1.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

```
                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
     RUN IDENT : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
     SEASON : FALL

 GAMMA1 =    0.80 , GAMMA2 =    0.35
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   3.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    5.20 CFS, RIVER Q =   0.11 CFS, TOTAL Q =   5.31 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   1.30 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
```

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	64.0	46.0		0.1	11.46	6.93		1.70
0.0	0.37	68.9	68.5	68.7	5.3	4.47	4.38	4.43	18.64
0.01	0.44	68.6	67.3	67.9	5.4	2.17	1.50	1.83	17.39
0.02	0.50	68.4	66.1	67.2	5.4	0.36	0.0	0.18	16.33
0.03	0.57	68.1	65.0	66.5	5.5	0.10	0.0	0.05	15.75
0.04	0.64	67.9	63.9	65.9	5.5	0.02	0.0	0.01	15.20
0.05	0.71	67.7	62.9	65.3	5.6	0.03	0.0	0.02	14.68
0.06	0.77	67.5	62.0	64.7	5.6	0.11	0.0	0.06	14.19
0.07	0.84	67.3	61.1	64.2	5.7	0.23	0.0	0.11	13.72
0.08	0.91	67.1	60.2	63.7	5.7	0.37	0.0	0.18	13.28
0.09	0.98	66.9	59.4	63.2	5.8	0.52	0.0	0.26	12.86
0.10	1.05	66.8	58.7	62.7	5.8	0.68	0.0	0.34	12.46
0.11	1.12	66.6	58.0	62.3	5.9	0.81	0.0	0.40	12.06
0.12	1.19	66.5	57.3	61.9	5.9	0.92	0.0	0.46	11.66
0.13	1.26	66.3	56.7	61.5	6.0	1.03	0.0	0.52	11.27
0.14	1.33	66.2	56.1	61.1	6.0	1.15	0.0	0.58	10.89
0.15	1.40	66.1	55.5	60.8	6.1	1.27	0.0	0.64	10.52
0.16	1.47	66.0	55.0	60.5	6.1	1.40	0.0	0.70	10.16
0.17	1.54	65.8	54.5	60.2	6.2	1.53	0.0	0.77	9.80
0.18	1.61	65.7	54.0	59.9	6.2	1.67	0.0	0.84	9.45
0.19	1.68	65.6	53.6	59.6	6.3	1.82	0.00	0.91	9.11
0.20	1.75	65.6	53.1	59.3	6.3	1.98	0.03	1.00	8.78
0.21	1.82	65.5	52.7	59.1	6.4	2.14	0.07	1.11	8.45
0.22	1.89	65.4	52.4	58.9	6.5	2.36	0.13	1.24	8.14
0.23	1.96	65.3	52.0	58.7	6.5	2.62	0.20	1.41	7.84
0.24	2.04	65.2	51.7	58.4	6.6	2.92	0.27	1.59	7.57
0.25	2.11	65.2	51.3	58.3	6.6	3.24	0.35	1.80	7.30

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TC COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.18	65.1	51.1	58.1	6.7	3.60	0.44	2.02	7.05
0.27	2.25	65.0	50.8	57.9	6.7	3.96	0.53	2.24	6.81
0.28	2.33	65.0	50.5	57.7	6.8	4.35	0.61	2.48	6.59
0.29	2.40	64.9	50.3	57.6	6.8	4.74	0.69	2.72	6.37
0.30	2.47	64.9	50.0	57.4	6.9	5.13	0.77	2.95	6.16
0.31	2.55	64.8	49.8	57.3	6.9	5.53	0.84	3.19	5.95
0.32	2.62	64.8	49.6	57.2	7.0	5.93	0.91	3.42	5.76
0.33	2.69	64.7	49.4	57.1	7.1	6.33	0.98	3.66	5.57
0.34	2.77	64.7	49.2	56.9	7.1	6.73	1.05	3.89	5.38
0.35	2.84	64.7	49.0	56.8	7.2	7.12	1.11	4.12	5.21
0.36	2.92	64.6	48.8	56.7	7.2	7.50	1.18	4.34	5.04
0.37	2.99	64.6	48.7	56.6	7.3	7.88	1.24	4.56	4.87
C.38	3.07	64.6	48.5	56.5	7.3	8.26	1.31	4.78	4.71
0.39	3.14	64.5	48.4	56.5	7.4	8.62	1.37	4.99	4.56
0.40	3.22	64.5	48.3	56.4	7.4	8.98	1.43	5.20	4.41
0.41	3.29	64.5	48.1	56.3	7.5	9.33	1.49	5.41	4.27
0.42	3.37	64.4	48.0	56.2	7.6	9.67	1.56	5.61	4.13
0.43	3.45	64.4	47.9	56.2	7.6	10.00	1.62	5.81	3.99
0.44	3.52	64.4	47.8	56.1	7.7	10.32	1.68	6.00	3.86
0.45	3.60	64.4	47.7	56.0	7.7	10.63	1.74	6.18	3.74
0.46	3.68	64.3	47.6	56.0	7.8	10.93	1.8C	6.37	3.61
C.47	3.75	64.3	47.5	55.9	7.8	11.22	1.86	6.54	3.50
0.48	3.83	64.3	47.4	55.9	7.9	11.50	1.93	6.72	3.42
C.49	3.91	64.3	47.3	55.8	8.0	11.78	1.99	6.88	3.35
0.50	3.98	64.3	47.3	55.8	8.0	12.04	2.05	7.04	3.28
0.51	4.06	64.3	47.2	55.7	8.1	12.30	2.11	7.20	3.21

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.14	64.2	47.1	55.7	8.1	12.54	2.18	7.36	3.14
0.53	4.22	64.2	47.1	55.7	8.2	12.77	2.26	7.52	3.08
0.54	4.30	64.2	47.0	55.6	8.3	13.00	2.33	7.67	3.02
0.55	4.38	64.2	47.0	55.6	8.3	13.22	2.41	7.81	2.96
0.56	4.45	64.2	46.9	55.5	8.4	13.42	2.49	7.96	2.90
0.57	4.53	64.2	46.8	55.5	8.4	13.62	2.57	8.10	2.84
0.58	4.61	64.2	46.8	55.5	8.5	13.81	2.65	8.23	2.79
0.59	4.69	64.2	46.8	55.5	8.6	13.99	2.73	8.36	2.74
0.60	4.77	64.2	46.7	55.4	8.6	14.16	2.82	8.49	2.69
0.61	4.85	64.1	46.7	55.4	8.7	14.32	2.90	8.61	2.64
0.62	4.93	64.1	46.6	55.4	8.7	14.47	2.98	8.72	2.59
0.63	5.01	64.1	46.6	55.4	8.8	14.61	3.06	8.84	2.54
0.64	5.09	64.1	46.6	55.3	8.9	14.75	3.14	8.94	2.50
0.65	5.17	64.1	46.5	55.3	8.9	14.87	3.21	9.04	2.46
0.66	5.26	64.1	46.5	55.3	9.0	14.99	3.29	9.14	2.42
0.67	5.34	64.1	46.5	55.3	9.0	15.09	3.37	9.23	2.37
0.68	5.42	64.1	46.5	55.3	9.1	15.19	3.44	9.32	2.34
0.69	5.50	64.1	46.4	55.3	9.2	15.28	3.51	9.40	2.30
0.70	5.58	64.1	46.4	55.2	9.2	15.37	3.58	9.47	2.26
0.71	5.66	64.1	46.4	55.2	9.3	15.44	3.65	9.54	2.22
0.72	5.75	64.1	46.4	55.2	9.3	15.50	3.72	9.61	2.19
0.73	5.83	64.1	46.3	55.2	9.4	15.56	3.78	9.67	2.16
0.74	5.91	64.1	46.3	55.2	9.5	15.61	3.84	9.73	2.12
0.75	5.99	64.1	46.3	55.2	9.5	15.65	3.91	9.78	2.09
0.76	6.08	64.1	46.3	55.2	9.6	15.69	3.96	9.83	2.06
0.77	6.16	64.1	46.3	55.2	9.7	15.71	4.02	9.87	2.03

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	6.24	64.1	46.3	55.2	9.7	15.73	4.08	9.90	2.00
0.79	6.33	64.1	46.2	55.1	9.8	15.74	4.13	9.94	1.98
0.80	6.41	64.0	46.2	55.1	9.8	15.74	4.18	9.96	1.95
0.81	6.49	64.0	46.2	55.1	9.9	15.74	4.23	9.99	1.92
0.82	6.58	64.0	46.2	55.1	10.0	15.73	4.28	10.01	1.90
0.83	6.66	64.0	46.2	55.1	10.0	15.71	4.33	10.02	1.87
0.84	6.75	64.0	46.2	55.1	10.1	15.69	4.37	10.03	1.85
0.85	6.83	64.0	46.2	55.1	10.2	15.66	4.42	10.04	1.82
0.86	6.92	64.0	46.2	55.1	10.2	15.62	4.46	10.04	1.80
0.87	7.00	64.0	46.2	55.1	10.3	15.58	4.50	10.04	1.78
0.88	7.09	64.0	46.1	55.1	10.4	15.54	4.53	10.03	1.76
0.89	7.17	64.0	46.1	55.1	10.4	15.48	4.57	10.03	1.74
0.90	7.26	64.0	46.1	55.1	10.5	15.42	4.60	10.01	1.72
0.91	7.35	64.0	46.1	55.1	10.5	15.36	4.64	10.00	1.70
0.92	7.43	64.0	46.1	55.1	10.6	15.29	4.67	9.98	1.70
0.93	7.52	64.0	46.1	55.1	10.7	15.22	4.69	9.96	1.70
0.94	7.61	64.0	46.1	55.1	10.7	15.14	4.72	9.93	1.70
0.95	7.69	64.0	46.1	55.1	10.8	15.06	4.75	9.90	1.70
0.96	7.78	64.0	46.1	55.1	10.9	14.98	4.77	9.87	1.70
0.97	7.87	64.0	46.1	55.1	10.9	14.89	4.79	9.84	1.70
0.98	7.95	64.0	46.1	55.0	11.0	14.80	4.81	9.80	1.70
0.99	8.04	64.0	46.1	55.0	11.1	14.70	4.83	9.77	1.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	2.47	4.47	1.36	5.83	2.50	1.80	0.10
0.0	0.37	36.51	3.21	39.73	14.88	54.60	4.65	8.17	97.93
0.01	0.44	34.73	3.19	37.92	13.88	51.79	5.02	8.07	91.33
0.02	0.50	32.70	3.12	35.82	13.03	48.86	5.21	7.97	85.29
0.03	0.57	31.09	3.10	34.18	12.57	46.75	5.04	7.89	80.49
0.04	0.64	29.68	3.08	32.76	12.13	44.89	4.89	7.80	76.34
0.05	0.71	28.39	3.07	31.46	11.71	43.17	4.75	7.72	72.54
0.06	0.77	27.18	3.06	30.24	11.32	41.56	4.61	7.64	68.96
0.07	0.84	26.02	3.05	29.07	10.95	40.02	4.48	7.57	65.54
0.08	0.91	24.89	3.04	27.93	10.60	38.53	4.35	7.49	62.22
0.09	0.98	23.79	3.03	26.82	10.26	37.09	4.22	7.41	58.99
0.10	1.05	22.73	3.02	25.75	9.94	35.69	4.09	7.34	55.86
0.11	1.12	21.73	3.01	24.74	9.62	34.36	3.98	7.26	52.93
0.12	1.19	20.79	3.00	23.79	9.31	33.10	3.88	7.19	50.19
0.13	1.26	19.90	3.00	22.90	9.00	31.90	3.80	7.12	47.62
0.14	1.33	19.07	3.00	22.06	8.69	30.76	3.72	7.05	45.21
0.15	1.40	18.28	2.99	21.27	8.40	29.67	3.66	6.98	42.94
0.16	1.47	17.54	2.99	20.53	8.11	28.64	3.61	6.91	40.82
0.17	1.54	16.83	3.00	19.83	7.82	27.65	3.57	6.84	38.81
0.18	1.61	16.17	3.00	19.17	7.54	26.71	3.53	6.78	36.93
0.19	1.68	15.54	3.00	18.54	7.27	25.81	3.51	6.71	35.15
0.20	1.75	14.94	3.01	17.95	7.00	24.95	3.50	6.65	33.48
0.21	1.82	14.37	3.01	17.39	6.74	24.13	3.50	6.59	31.89
0.22	1.89	13.83	3.02	16.84	6.49	23.34	3.49	6.53	30.37
0.23	1.96	13.30	3.02	16.32	6.26	22.58	3.48	6.46	28.92
0.24	2.04	12.79	3.02	15.82	6.04	21.86	3.46	6.40	27.53
0.25	2.11	12.30	3.03	15.33	5.83	21.16	3.44	6.34	26.19

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.18	11.83	3.03	14.86	5.63	20.48	3.41	6.29	24.90
0.27	2.25	11.37	3.03	14.40	5.44	19.84	3.38	6.23	23.66
0.28	2.33	10.93	3.03	13.95	5.26	19.21	3.34	6.17	22.48
0.29	2.40	10.51	3.03	13.53	5.08	18.62	3.31	6.11	21.36
0.30	2.47	10.11	3.03	13.13	4.91	18.05	3.27	6.06	20.30
0.31	2.55	9.72	3.03	12.75	4.75	17.51	3.23	6.00	19.30
0.32	2.62	9.36	3.03	12.39	4.59	16.99	3.20	5.95	18.35
0.33	2.69	9.01	3.04	12.05	4.44	16.49	3.16	5.90	17.46
0.34	2.77	8.68	3.04	11.72	4.30	16.02	3.12	5.84	16.61
0.35	2.84	8.37	3.05	11.41	4.16	15.57	3.09	5.79	15.81
0.36	2.92	8.06	3.05	11.11	4.02	15.13	3.06	5.74	15.05
0.37	2.99	7.77	3.06	10.83	3.89	14.72	3.04	5.69	14.33
0.38	3.07	7.50	3.06	10.56	3.76	14.32	3.01	5.64	13.65
0.39	3.14	7.23	3.07	10.30	3.64	13.94	2.99	5.59	13.01
0.40	3.22	6.98	3.08	10.06	3.52	13.58	2.96	5.54	12.39
0.41	3.29	6.74	3.08	9.82	3.40	13.23	2.94	5.50	11.81
0.42	3.37	6.51	3.09	9.60	3.29	12.89	2.91	5.45	11.26
0.43	3.45	6.28	3.10	9.38	3.19	12.57	2.88	5.41	10.74
0.44	3.52	6.07	3.11	9.18	3.08	12.26	2.85	5.36	10.24
0.45	3.60	5.86	3.12	8.98	2.98	11.96	2.83	5.32	9.77
0.46	3.68	5.67	3.12	8.79	2.88	11.68	2.80	5.27	9.32
0.47	3.75	5.48	3.13	8.61	2.79	11.40	2.77	5.23	8.90
0.48	3.83	5.30	3.14	8.44	2.70	11.14	2.75	5.19	8.49
0.49	3.91	5.12	3.15	8.28	2.61	10.88	2.72	5.14	8.10
0.50	3.98	4.96	3.16	8.12	2.52	10.64	2.70	5.10	7.74
0.51	4.06	4.79	3.17	7.97	2.44	10.41	2.68	5.06	7.39

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.14	4.64	3.18	7.82	2.36	10.18	2.66	5.02	7.06
0.53	4.22	4.49	3.19	7.68	2.29	9.97	2.64	4.98	6.74
0.54	4.30	4.35	3.20	7.55	2.21	9.76	2.61	4.94	6.44
0.55	4.38	4.21	3.21	7.42	2.14	9.56	2.59	4.90	6.16
0.56	4.45	4.08	3.22	7.30	2.08	9.37	2.57	4.86	5.88
0.57	4.53	3.95	3.23	7.18	2.01	9.19	2.55	4.83	5.62
0.58	4.61	3.82	3.24	7.07	1.95	9.02	2.53	4.79	5.38
0.59	4.69	3.71	3.25	6.96	1.89	8.85	2.52	4.75	5.14
0.60	4.77	3.59	3.26	6.85	1.83	8.69	2.52	4.72	4.92
0.61	4.85	3.48	3.27	6.75	1.78	8.53	2.51	4.68	4.70
0.62	4.93	3.37	3.28	6.66	1.73	8.38	2.51	4.65	4.50
0.63	5.01	3.27	3.29	6.56	1.68	8.24	2.50	4.61	4.30
0.64	5.09	3.17	3.30	6.48	1.63	8.10	2.50	4.58	4.12
0.65	5.17	3.07	3.31	6.39	1.58	7.97	2.50	4.54	3.94
0.66	5.26	2.98	3.33	6.31	1.53	7.84	2.50	4.51	3.77
0.67	5.34	2.89	3.34	6.23	1.49	7.72	2.50	4.48	3.61
0.68	5.42	2.81	3.35	6.15	1.45	7.60	2.50	4.44	3.46
0.69	5.50	2.72	3.36	6.08	1.41	7.49	2.50	4.41	3.31
0.70	5.58	2.64	3.37	6.01	1.37	7.38	2.50	4.38	3.17
0.71	5.66	2.56	3.38	5.94	1.33	7.27	2.50	4.35	3.04
0.72	5.75	2.49	3.39	5.88	1.30	7.17	2.50	4.32	2.91
0.73	5.83	2.42	3.40	5.81	1.26	7.08	2.50	4.29	2.79
0.74	5.91	2.35	3.41	5.75	1.23	6.98	2.50	4.26	2.67
0.75	5.99	2.28	3.42	5.70	1.20	6.89	2.50	4.23	2.56
0.76	6.08	2.21	3.43	5.64	1.16	6.80	2.50	4.20	2.45
0.77	6.16	2.15	3.44	5.59	1.13	6.72	2.50	4.17	2.35

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

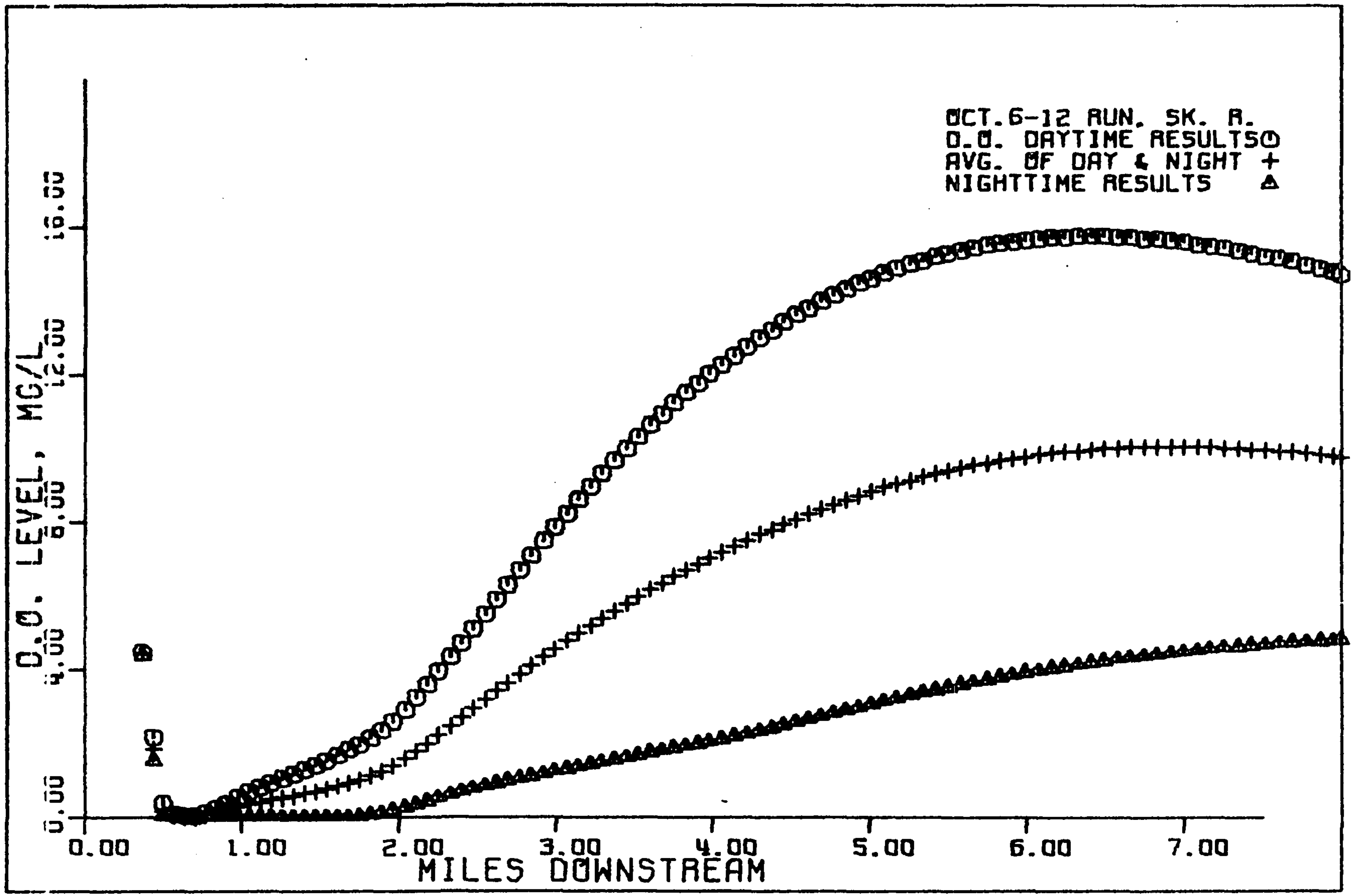
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	6.24	2.09	3.45	5.53	1.11	6.64	2.50	4.14	2.25
0.79	6.33	2.03	3.46	5.48	1.08	6.56	2.50	4.11	2.16
0.80	6.41	1.97	3.47	5.44	1.05	6.49	2.50	4.08	2.07
0.81	6.49	1.91	3.48	5.39	1.02	6.41	2.50	4.05	1.98
0.82	6.58	1.86	3.49	5.35	1.00	6.34	2.50	4.03	1.90
0.83	6.66	1.81	3.50	5.30	0.97	6.28	2.50	4.00	1.82
0.84	6.75	1.75	3.51	5.26	0.95	6.21	2.50	3.97	1.75
0.85	6.83	1.71	3.52	5.22	0.93	6.15	2.50	3.94	1.68
0.86	6.92	1.66	3.53	5.18	0.91	6.09	2.50	3.92	1.61
0.87	7.00	1.61	3.53	5.15	0.88	6.03	2.50	3.89	1.54
0.88	7.09	1.57	3.54	5.11	0.86	5.97	2.50	3.87	1.48
0.89	7.17	1.52	3.55	5.08	0.84	5.92	2.50	3.84	1.42
0.90	7.26	1.48	3.56	5.04	0.82	5.87	2.50	3.82	1.37
0.91	7.35	1.44	3.57	5.01	0.81	5.82	2.50	3.79	1.31
0.92	7.43	1.40	3.58	4.98	0.79	5.77	2.50	3.77	1.26
0.93	7.52	1.36	3.59	4.95	0.77	5.72	2.50	3.74	1.21
0.94	7.61	1.32	3.60	4.92	0.75	5.68	2.50	3.72	1.16
0.95	7.69	1.29	3.61	4.89	0.74	5.63	2.50	3.69	1.11
0.96	7.78	1.25	3.62	4.87	0.72	5.59	2.50	3.67	1.07
0.97	7.87	1.22	3.62	4.84	0.71	5.55	2.50	3.65	1.03
0.98	7.95	1.19	3.63	4.82	0.69	5.51	2.50	3.63	0.99
0.99	8.04	1.15	3.64	4.79	0.68	5.47	2.50	3.60	0.95

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

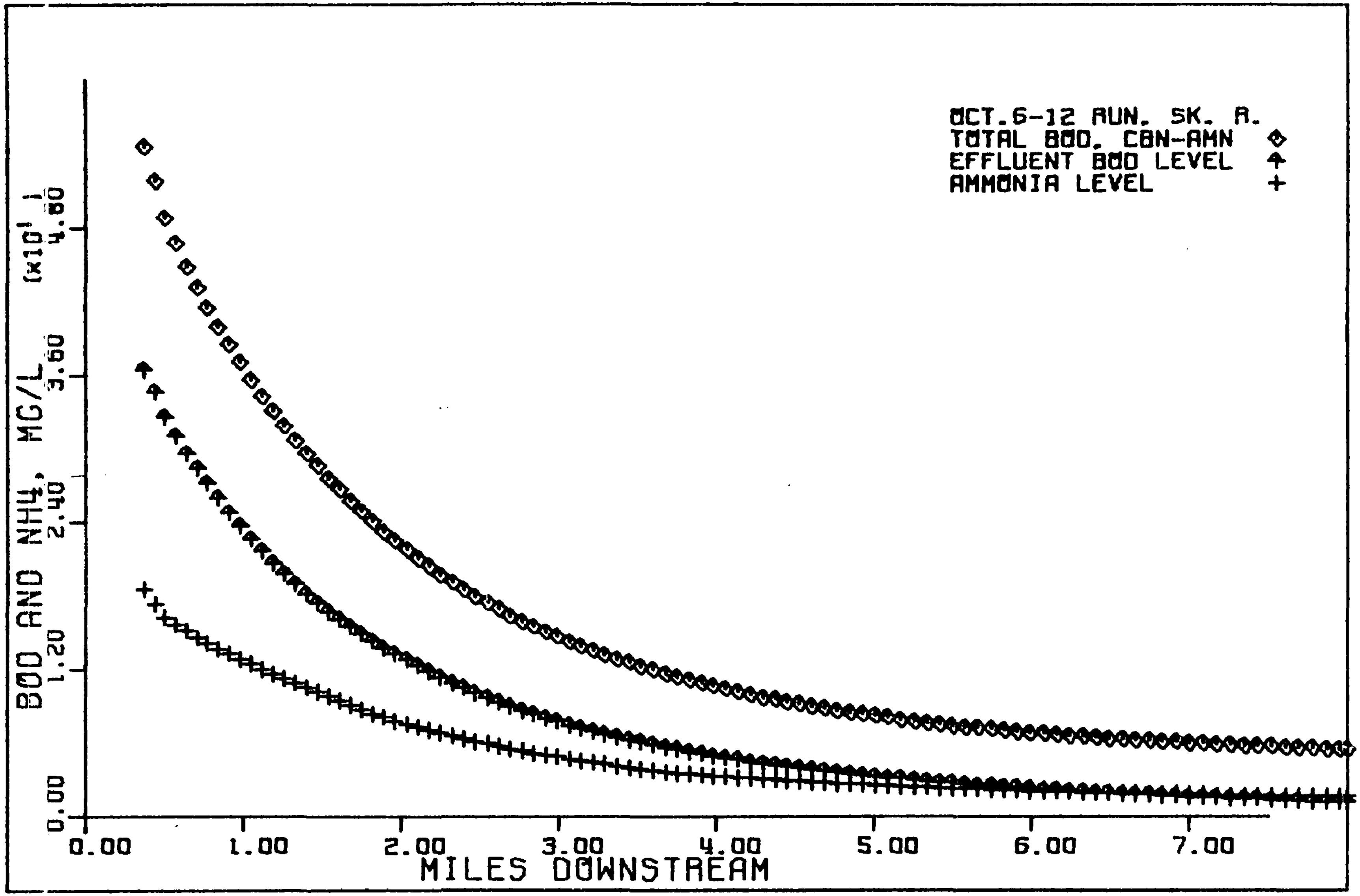
STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD AND OTHER DATA FOR OCT. 6-12,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	4.47	0.37	0.0	4.38	0.37	0.0
MINIMUM DO, MG/L	0.02	0.64	0.04	0.0	0.50	0.02
FINAL DO, MG/L	15.74	6.41	0.80	4.18	6.41	0.80
DO DEFICIT						
INITIAL, MG/L	4.19	0.37	0.0	4.32	0.37	0.0
FINAL, MG/L	-6.59	6.41	0.80	7.33	6.41	0.80
RIVER DISCHARGE						
INITIAL, CFS	5.31	0.37	0.0	5.31	0.37	0.0
FINAL, CFS	9.84	6.41	0.80	9.84	6.41	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	68.90	0.37	0.0	68.52	0.37	0.0
FINAL, DEG F	64.05	6.41	0.80	46.23	6.41	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	36.51	0.37	0.0	36.51	0.37	0.0
FINAL BOD, MG/L	1.21	6.41	0.80	2.73	6.41	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.12	0.37	0.0	0.12	0.37	0.0
FINAL BOD IN RIVER	3.04	6.41	0.80	3.90	6.41	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	14.88	0.37	0.0	14.88	0.37	0.0
FINAL BOD, MG/L	0.35	6.41	0.80	1.75	6.41	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	53.86	0.37	0.0	55.35	0.37	0.0
FINAL VALUE, MG/L	4.60	6.41	0.80	8.38	6.41	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	18.64	0.37	0.0	18.64	0.37	0.0
FINAL VALUE, MG/L	1.70	6.41	0.80	2.20	6.41	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.65	C.37	0.0	4.65	0.37	0.0
FINAL VALUE, MG/L	2.50	6.41	0.80	2.50	6.41	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	8.17	0.37	0.0	8.17	0.37	0.0
FINAL VALUE, MG/L	3.86	6.41	0.80	4.30	6.41	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	97.93	0.37	0.0	97.93	0.37	0.0
FINAL PERCENT	0.73	6.41	0.80	3.41	6.41	0.80



ØCT.6-12 RUN. SK. R.
D.Ø. DAYTIME RESULTS ⊙
AVG. ØF DAY & NIGHT +
NIGHTTIME RESULTS △
D.Ø. LEVEL, MG/L
MILES DOWNSTREAM
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00


OCT.6-12 RUN. SK. R.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10¹)
0.00
1.20
2.40
3.60
4.80
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
MILES DOWNSTREAM

G. Simulation Results for October 20-30, 1966

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.13	72.00	50.00	0.0	75.00	0.080	0.0	30.00	3.50	10.70	100.00	0.0	0.0	0.80	0.40

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
62.00	42.00	120.00	50.00	2.00	0.140	0.0	1.40	1.20	1.60	0.10	50.00	3.00	0.50	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.82	0.65	80.00	50.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.200	2.000	0.300	1.020

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
63.00	42.00	2.500	0.0	0.0	2.500	0.100	0.40	1.10	1.60	2.40	1.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLOCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
     RUN IDENT : BOD AND CTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
     SEASON : FALL

 GAMMA1 =   0.80 , GAMMA2 =   0.40
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   3.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   4.85 CFS, RIVER Q =   0.82 CFS, TOTAL Q =   5.67 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   1.10 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	62.0	42.0		0.8	11.26	6.11		1.40
0.0	0.37	70.6	67.7	69.1	5.7	5.21	4.46	4.84	25.86
0.01	0.44	70.1	66.2	68.2	5.7	4.01	3.14	3.58	25.48
0.02	0.51	69.7	64.9	67.3	5.8	2.98	1.68	2.33	25.12
0.03	0.58	69.4	63.6	66.5	5.8	2.16	0.54	1.35	24.78
0.04	0.64	69.0	62.4	65.7	5.8	1.52	0.0	0.76	24.47
0.05	0.71	68.7	61.2	65.0	5.9	1.08	0.0	0.54	24.19
0.06	0.78	68.3	60.2	64.3	5.9	0.82	0.0	0.41	23.93
0.07	0.85	68.0	59.2	63.6	6.0	0.68	0.0	0.34	23.68
0.08	0.92	67.8	58.2	63.0	6.0	0.63	0.0	0.32	23.44
0.09	0.99	67.5	57.3	62.4	6.1	0.64	0.0	0.32	23.20
0.10	1.06	67.2	56.4	61.8	6.1	0.70	0.0	0.35	22.97
0.11	1.13	67.0	55.6	61.3	6.2	0.79	0.0	0.40	22.74
0.12	1.20	66.8	54.9	60.8	6.2	0.91	0.0	0.45	22.52
0.13	1.27	66.6	54.2	60.4	6.3	1.04	0.0	0.52	22.30
0.14	1.35	66.4	53.5	59.9	6.3	1.18	0.0	0.59	22.07
0.15	1.42	66.2	52.8	59.5	6.3	1.33	0.0	0.67	21.85
0.16	1.49	66.0	52.2	59.1	6.4	1.49	0.0	0.75	21.63
0.17	1.56	65.8	51.7	58.7	6.4	1.66	0.0	0.83	21.41
0.18	1.63	65.7	51.1	58.4	6.5	1.82	0.0	0.91	21.19
0.19	1.70	65.5	50.6	58.1	6.5	1.99	0.01	1.00	20.97
0.20	1.77	65.4	50.1	57.8	6.6	2.16	0.03	1.09	20.75
0.21	1.85	65.3	49.7	57.5	6.6	2.35	0.05	1.20	20.53
0.22	1.92	65.1	49.2	57.2	6.7	2.55	0.08	1.31	20.32
0.23	1.99	65.0	48.8	56.9	6.7	2.76	0.11	1.43	20.11
0.24	2.07	64.9	48.5	56.7	6.8	2.98	0.14	1.56	19.91
0.25	2.14	64.8	48.1	56.4	6.8	3.21	0.17	1.69	19.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.21	64.7	47.8	56.2	6.9	3.44	0.20	1.82	19.51
0.27	2.29	64.6	47.4	56.0	6.9	3.68	0.23	1.95	19.31
0.28	2.36	64.5	47.1	55.8	7.0	3.92	0.26	2.09	19.12
0.29	2.43	64.4	46.8	55.6	7.0	4.17	0.29	2.23	18.93
0.30	2.51	64.3	46.6	55.5	7.1	4.41	0.32	2.37	18.74
0.31	2.58	64.3	46.3	55.3	7.1	4.66	0.35	2.51	18.56
0.32	2.66	64.2	46.1	55.1	7.2	4.91	0.38	2.64	18.38
0.33	2.73	64.1	45.8	55.0	7.2	5.16	0.41	2.78	18.20
0.34	2.80	64.1	45.6	54.9	7.2	5.40	0.44	2.92	18.02
0.35	2.88	64.0	45.4	54.7	7.3	5.65	0.47	3.06	17.85
0.36	2.95	64.0	45.2	54.6	7.3	5.89	0.50	3.20	17.68
0.37	3.03	63.9	45.1	54.5	7.4	6.14	0.53	3.33	17.51
0.38	3.11	63.8	44.9	54.4	7.4	6.38	0.56	3.47	17.35
0.39	3.18	63.8	44.7	54.3	7.5	6.62	0.59	3.61	17.18
0.40	3.26	63.8	44.6	54.2	7.5	6.85	0.63	3.74	17.02
0.41	3.33	63.7	44.4	54.1	7.6	7.09	0.67	3.88	16.86
0.42	3.41	63.7	44.3	54.0	7.6	7.32	0.71	4.01	16.71
0.43	3.49	63.6	44.2	53.9	7.7	7.54	0.75	4.15	16.55
0.44	3.56	63.6	44.0	53.8	7.7	7.77	0.80	4.28	16.40
0.45	3.64	63.6	43.9	53.7	7.8	7.99	0.84	4.42	16.24
0.46	3.72	63.5	43.8	53.7	7.8	8.21	0.89	4.55	16.09
0.47	3.79	63.5	43.7	53.6	7.9	8.42	0.93	4.67	15.95
0.48	3.87	63.5	43.6	53.6	7.9	8.63	0.97	4.80	15.80
0.49	3.95	63.5	43.5	53.5	8.0	8.84	1.02	4.93	15.65
0.50	4.03	63.4	43.4	53.4	8.0	9.04	1.06	5.05	15.51
0.51	4.10	63.4	43.4	53.4	8.1	9.24	1.10	5.17	15.37

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.18	63.4	43.3	53.3	8.1	9.43	1.15	5.29	15.23
0.53	4.26	63.4	43.2	53.3	8.2	9.62	1.19	5.41	15.09
0.54	4.34	63.3	43.2	53.2	8.2	9.81	1.23	5.52	14.95
0.55	4.42	63.3	43.1	53.2	8.3	9.99	1.27	5.63	14.81
0.56	4.50	63.3	43.0	53.2	8.3	10.16	1.32	5.74	14.68
0.57	4.58	63.3	43.0	53.1	8.4	10.34	1.36	5.85	14.55
0.58	4.65	63.3	42.9	53.1	8.5	10.50	1.40	5.95	14.42
0.59	4.73	63.3	42.9	53.1	8.5	10.67	1.44	6.05	14.29
0.60	4.81	63.2	42.8	53.0	8.6	10.82	1.47	6.15	14.16
0.61	4.89	63.2	42.8	53.0	8.6	10.98	1.51	6.25	14.03
0.62	4.97	63.2	42.7	53.0	8.7	11.13	1.55	6.34	13.90
0.63	5.05	63.2	42.7	52.9	8.7	11.27	1.59	6.43	13.78
0.64	5.13	63.2	42.6	52.9	8.8	11.41	1.63	6.52	13.66
0.65	5.21	63.2	42.6	52.9	8.8	11.54	1.66	6.60	13.53
0.66	5.30	63.2	42.6	52.9	8.9	11.67	1.70	6.68	13.41
0.67	5.38	63.2	42.5	52.9	8.9	11.79	1.73	6.76	13.29
0.68	5.46	63.2	42.5	52.8	9.0	11.91	1.77	6.84	13.18
0.69	5.54	63.1	42.5	52.8	9.0	12.02	1.80	6.91	13.06
0.70	5.62	63.1	42.5	52.8	9.1	12.13	1.84	6.98	12.94
0.71	5.70	63.1	42.4	52.8	9.1	12.23	1.87	7.05	12.83
0.72	5.78	63.1	42.4	52.8	9.2	12.33	1.90	7.12	12.72
0.73	5.86	63.1	42.4	52.7	9.2	12.42	1.94	7.18	12.60
0.74	5.95	63.1	42.4	52.7	9.3	12.51	1.97	7.24	12.49
0.75	6.03	63.1	42.3	52.7	9.3	12.59	2.00	7.30	12.38
0.76	6.11	63.1	42.3	52.7	9.4	12.67	2.03	7.35	12.28
0.77	6.19	63.1	42.3	52.7	9.5	12.74	2.07	7.40	12.17

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	6.28	63.1	42.3	52.7	9.5	12.80	2.10	7.45	12.06
0.79	6.36	63.1	42.3	52.7	9.6	12.86	2.13	7.50	11.96
0.80	6.44	63.1	42.3	52.7	9.6	12.92	2.17	7.54	11.85
0.81	6.53	63.1	42.2	52.7	9.7	12.96	2.20	7.58	11.75
0.82	6.61	63.1	42.2	52.6	9.7	13.01	2.23	7.62	11.65
0.83	6.69	63.1	42.2	52.6	9.8	13.05	2.27	7.66	11.55
0.84	6.78	63.1	42.2	52.6	9.8	13.08	2.30	7.69	11.45
0.85	6.86	63.1	42.2	52.6	9.9	13.11	2.34	7.72	11.35
0.86	6.95	63.1	42.2	52.6	9.9	13.13	2.37	7.75	11.26
0.87	7.03	63.1	42.2	52.6	10.0	13.15	2.41	7.78	11.16
0.88	7.11	63.0	42.2	52.6	10.0	13.16	2.44	7.80	11.07
0.89	7.20	63.0	42.2	52.6	10.1	13.17	2.48	7.82	10.97
0.90	7.28	63.0	42.1	52.6	10.2	13.18	2.51	7.84	10.88
0.91	7.37	63.0	42.1	52.6	10.2	13.17	2.55	7.86	10.79
0.92	7.45	63.0	42.1	52.6	10.3	13.17	2.58	7.87	10.70
0.93	7.54	63.0	42.1	52.6	10.3	13.16	2.62	7.89	10.61
0.94	7.63	63.0	42.1	52.6	10.4	13.15	2.65	7.90	10.52
0.95	7.71	63.0	42.1	52.6	10.4	13.13	2.69	7.91	10.44
0.96	7.80	63.0	42.1	52.6	10.5	13.10	2.72	7.91	10.35
0.97	7.88	63.0	42.1	52.6	10.5	13.08	2.76	7.92	10.27
0.98	7.97	63.0	42.1	52.6	10.6	13.05	2.79	7.92	10.18
0.99	8.06	63.0	42.1	52.6	10.7	13.01	2.83	7.92	10.10

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	4.82	6.82	1.28	8.10	1.20	1.60	0.10
0.0	0.37	85.60	5.69	91.29	23.58	114.88	3.17	9.38	85.54
0.01	0.44	83.15	5.64	88.79	23.24	112.04	3.10	9.28	79.84
0.02	0.51	80.48	5.58	86.07	22.91	108.98	3.03	9.18	74.64
0.03	0.58	77.96	5.52	83.49	22.60	106.08	2.95	9.08	69.88
0.04	0.64	75.57	5.47	81.04	22.32	103.36	2.85	8.98	65.51
0.05	0.71	73.49	5.44	78.93	22.06	100.99	2.76	8.89	61.90
0.06	0.78	71.50	5.41	76.91	21.82	98.74	2.65	8.80	58.54
0.07	0.85	69.60	5.39	74.99	21.59	96.58	2.55	8.71	55.43
0.08	0.92	67.78	5.37	73.15	21.37	94.52	2.45	8.63	52.53
0.09	0.99	66.03	5.35	71.38	21.16	92.54	2.35	8.54	49.82
0.10	1.06	64.35	5.33	69.69	20.95	90.64	2.26	8.46	47.30
0.11	1.13	62.74	5.32	68.06	20.74	88.80	2.18	8.38	44.94
0.12	1.20	61.19	5.30	66.50	20.54	87.03	2.10	8.30	42.72
0.13	1.27	59.70	5.29	64.99	20.33	85.33	2.03	8.23	40.65
0.14	1.35	58.26	5.28	63.55	20.13	83.68	1.97	8.15	38.71
0.15	1.42	56.87	5.28	62.15	19.93	82.08	1.91	8.07	36.88
0.16	1.49	55.54	5.27	60.81	19.73	80.53	1.86	8.00	35.16
0.17	1.56	54.24	5.27	59.51	19.53	79.04	1.81	7.93	33.54
0.18	1.63	53.00	5.26	58.26	19.32	77.58	1.77	7.86	32.02
0.19	1.70	51.79	5.26	57.05	19.12	76.17	1.74	7.79	30.58
0.20	1.77	50.62	5.26	55.88	18.92	74.80	1.71	7.72	29.22
0.21	1.85	49.48	5.26	54.74	18.73	73.47	1.68	7.65	27.93
0.22	1.92	48.38	5.26	53.64	18.53	72.17	1.66	7.58	26.70
0.23	1.99	47.31	5.26	52.56	18.34	70.91	1.63	7.52	25.53
0.24	2.07	46.26	5.26	51.52	18.15	69.67	1.60	7.45	24.41
0.25	2.14	45.24	5.26	50.50	17.97	68.47	1.58	7.39	23.35

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.21	44.25	5.26	49.50	17.79	67.29	1.55	7.32	22.33
0.27	2.29	43.28	5.26	48.54	17.61	66.15	1.53	7.26	21.36
0.28	2.36	42.33	5.26	47.59	17.44	65.03	1.51	7.20	20.44
0.29	2.43	41.41	5.26	46.67	17.26	63.93	1.48	7.14	19.55
0.30	2.51	40.51	5.26	45.77	17.09	62.86	1.46	7.08	18.70
0.31	2.58	39.63	5.26	44.89	16.93	61.82	1.43	7.02	17.89
0.32	2.66	38.77	5.26	44.04	16.76	60.80	1.41	6.96	17.12
0.33	2.73	37.94	5.27	43.20	16.60	59.80	1.39	6.90	16.37
0.34	2.80	37.12	5.27	42.38	16.44	58.82	1.37	6.84	15.66
0.35	2.88	36.32	5.27	41.59	16.28	57.87	1.34	6.78	14.98
0.36	2.95	35.54	5.27	40.81	16.13	56.93	1.32	6.73	14.33
0.37	3.03	34.78	5.27	40.05	15.97	56.02	1.31	6.67	13.71
0.38	3.11	34.03	5.27	39.31	15.82	55.13	1.31	6.62	13.12
0.39	3.18	33.31	5.28	38.59	15.67	54.26	1.30	6.56	12.55
0.40	3.26	32.61	5.28	37.89	15.52	53.41	1.30	6.51	12.01
0.41	3.33	31.93	5.28	37.21	15.38	52.59	1.29	6.46	11.50
0.42	3.41	31.26	5.29	36.55	15.24	51.78	1.28	6.40	11.02
0.43	3.49	30.61	5.29	35.90	15.09	50.99	1.28	6.35	10.55
0.44	3.56	29.98	5.29	35.27	14.95	50.23	1.27	6.30	10.11
0.45	3.64	29.36	5.30	34.66	14.81	49.48	1.26	6.25	9.69
0.46	3.72	28.77	5.30	34.07	14.68	48.75	1.26	6.20	9.28
0.47	3.79	28.18	5.31	33.49	14.54	48.03	1.25	6.15	8.90
0.48	3.87	27.61	5.32	32.93	14.41	47.33	1.25	6.10	8.53
0.49	3.95	27.06	5.32	32.38	14.28	46.65	1.24	6.06	8.18
0.50	4.03	26.51	5.33	31.84	14.14	45.99	1.23	6.01	7.85
0.51	4.10	25.99	5.34	31.32	14.01	45.34	1.23	5.96	7.53

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.18	25.47	5.34	30.81	13.89	44.70	1.22	5.92	7.23
0.53	4.26	24.97	5.35	30.32	13.76	44.08	1.22	5.87	6.93
0.54	4.34	24.48	5.36	29.83	13.63	43.47	1.21	5.83	6.66
0.55	4.42	24.00	5.37	29.36	13.51	42.87	1.20	5.78	6.39
0.56	4.50	23.53	5.37	28.90	13.39	42.29	1.20	5.74	6.14
0.57	4.58	23.07	5.38	28.45	13.27	41.72	1.20	5.69	5.89
0.58	4.65	22.63	5.39	28.02	13.15	41.16	1.20	5.65	5.66
0.59	4.73	22.19	5.40	27.59	13.03	40.62	1.20	5.61	5.44
0.60	4.81	21.77	5.41	27.17	12.91	40.09	1.20	5.57	5.22
0.61	4.89	21.35	5.42	26.77	12.80	39.56	1.20	5.53	5.02
0.62	4.97	20.94	5.43	26.37	12.68	39.05	1.20	5.49	4.82
0.63	5.05	20.55	5.44	25.98	12.57	38.55	1.20	5.45	4.64
0.64	5.13	20.16	5.45	25.61	12.45	38.06	1.20	5.41	4.46
0.65	5.21	19.78	5.46	25.24	12.34	37.58	1.20	5.37	4.28
0.66	5.30	19.41	5.46	24.88	12.23	37.11	1.20	5.33	4.12
0.67	5.38	19.05	5.47	24.52	12.12	36.65	1.20	5.29	3.96
0.68	5.46	18.70	5.49	24.18	12.02	36.20	1.20	5.25	3.81
0.69	5.54	18.35	5.50	23.84	11.91	35.75	1.20	5.21	3.66
0.70	5.62	18.01	5.51	23.52	11.80	35.32	1.20	5.18	3.52
0.71	5.70	17.68	5.52	23.20	11.70	34.90	1.20	5.14	3.39
0.72	5.78	17.36	5.53	22.88	11.60	34.48	1.20	5.10	3.26
0.73	5.86	17.04	5.54	22.58	11.50	34.07	1.20	5.07	3.14
0.74	5.95	16.73	5.55	22.28	11.39	33.67	1.20	5.03	3.02
0.75	6.03	16.43	5.56	21.99	11.29	33.28	1.20	5.00	2.91
0.76	6.11	16.13	5.57	21.70	11.19	32.89	1.20	4.96	2.80
0.77	6.19	15.84	5.58	21.42	11.10	32.52	1.20	4.93	2.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

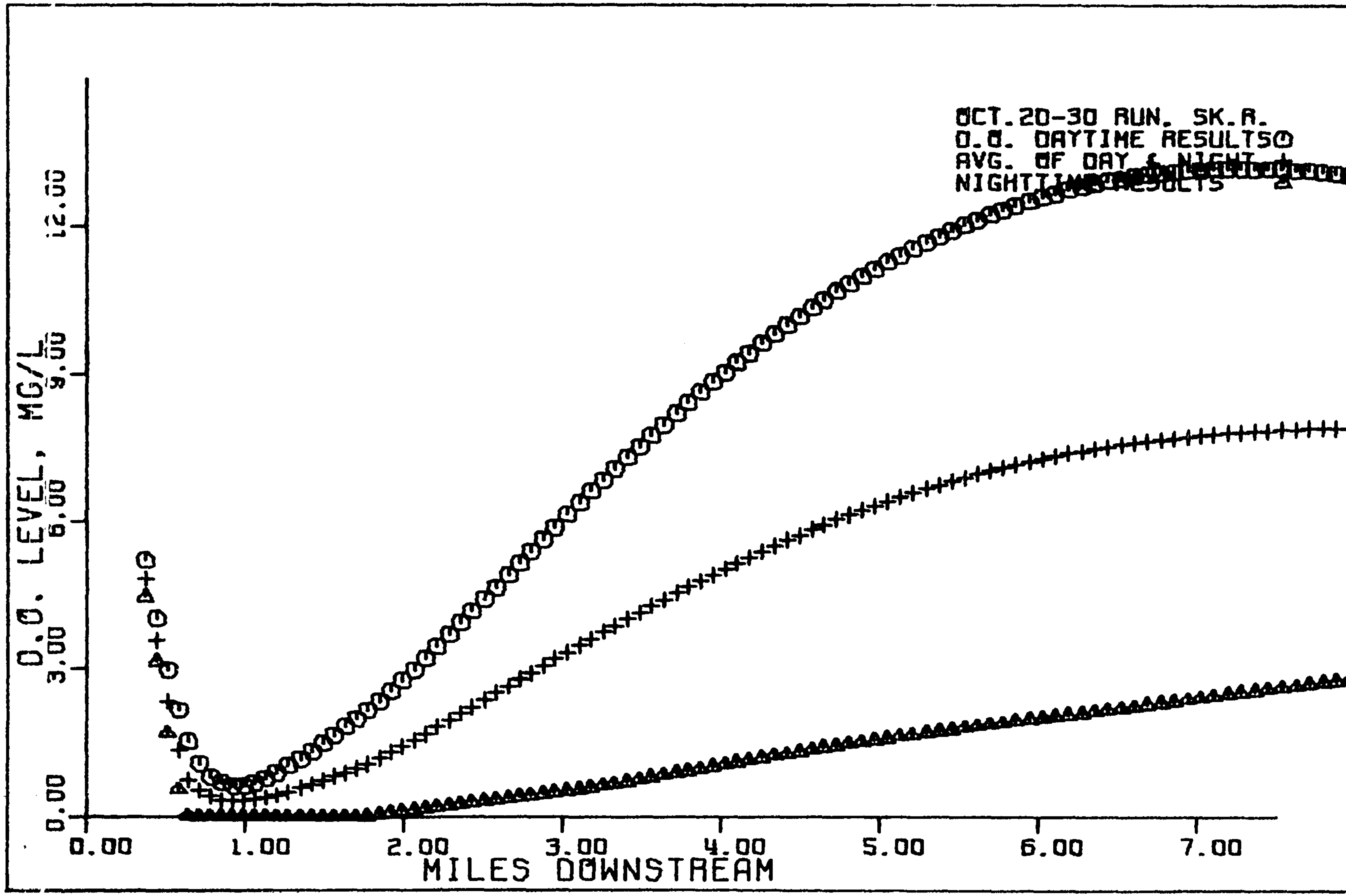
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	6.28	15.56	5.59	21.15	11.00	32.15	1.20	4.89	2.60
0.79	6.36	15.28	5.60	20.88	10.90	31.79	1.20	4.86	2.50
0.80	6.44	15.00	5.62	20.62	10.81	31.43	1.20	4.83	2.41
0.81	6.53	14.74	5.63	20.36	10.72	31.08	1.20	4.79	2.32
0.82	6.61	14.48	5.64	20.12	10.63	30.74	1.20	4.76	2.23
0.83	6.69	14.22	5.65	19.87	10.53	30.41	1.20	4.73	2.15
0.84	6.78	13.97	5.66	19.63	10.44	30.08	1.20	4.70	2.07
0.85	6.86	13.73	5.67	19.40	10.35	29.75	1.20	4.66	2.00
0.86	6.95	13.49	5.68	19.17	10.27	29.44	1.20	4.63	1.92
0.87	7.03	13.25	5.70	18.95	10.18	29.13	1.20	4.60	1.85
0.88	7.11	13.02	5.71	18.73	10.09	28.82	1.20	4.57	1.79
0.89	7.20	12.80	5.72	18.52	10.01	28.53	1.20	4.54	1.72
0.90	7.28	12.57	5.73	18.31	9.92	28.23	1.20	4.51	1.66
0.91	7.37	12.36	5.74	18.10	9.84	27.95	1.20	4.48	1.60
0.92	7.45	12.15	5.76	17.90	9.76	27.66	1.20	4.45	1.54
0.93	7.54	11.94	5.77	17.71	9.68	27.39	1.20	4.42	1.49
0.94	7.63	11.73	5.78	17.52	9.60	27.11	1.20	4.39	1.43
0.95	7.71	11.53	5.79	17.33	9.52	26.85	1.20	4.37	1.38
0.96	7.80	11.34	5.81	17.15	9.44	26.59	1.20	4.34	1.33
0.97	7.88	11.15	5.82	16.97	9.36	26.33	1.20	4.31	1.29
0.98	7.97	10.96	5.83	16.79	9.29	26.08	1.20	4.28	1.24
0.99	8.06	10.78	5.84	16.62	9.21	25.83	1.20	4.26	1.20

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

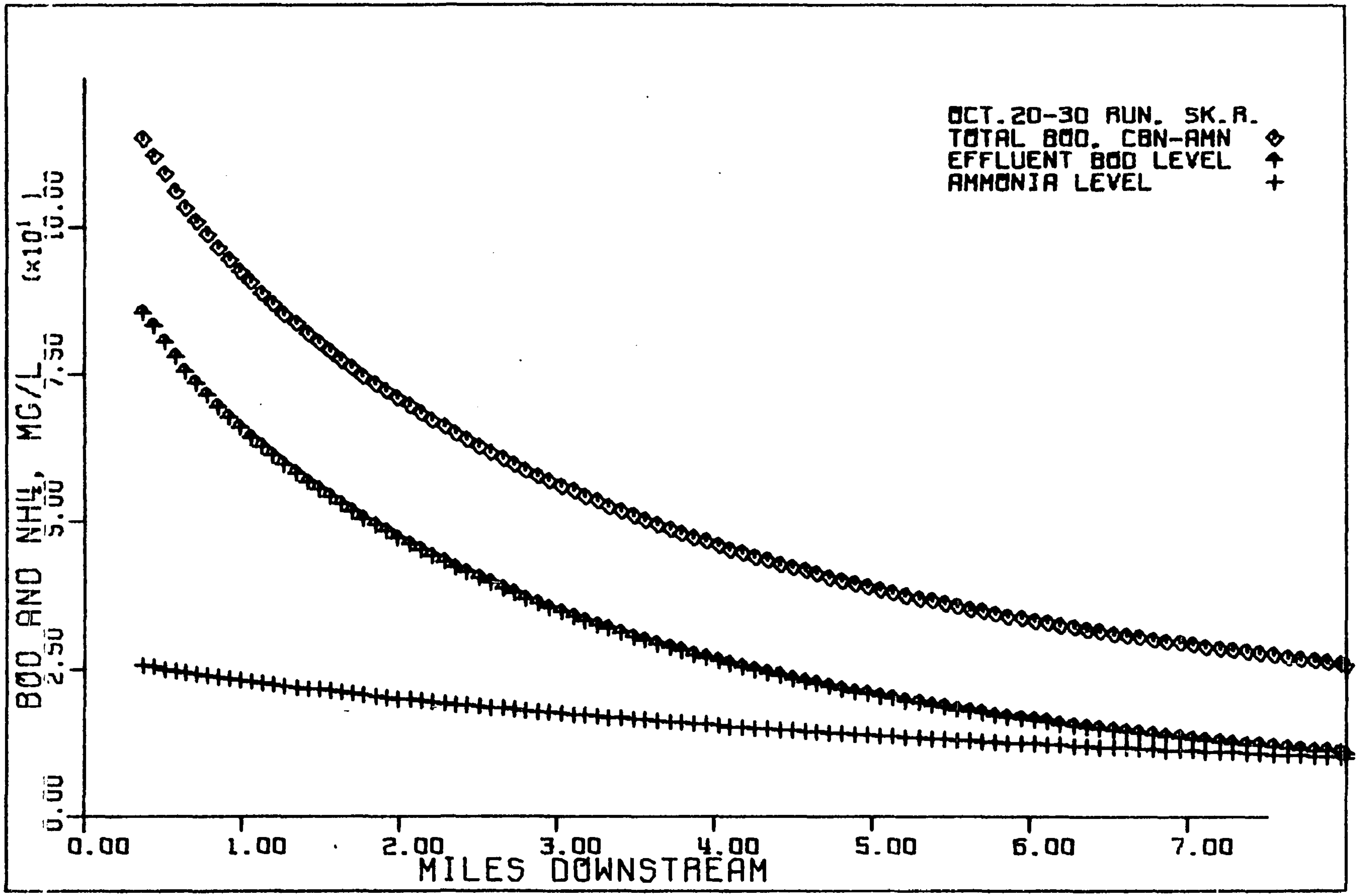
STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD AND OTHER DATA FOR OCT. 20-30,1966, PARTIAL SEC. TREAT.
SEASON : FALL
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	5.21	0.37	0.0	4.46	0.37	0.0
MINIMUM DO, MG/L	0.63	0.92	0.08	0.0	0.64	0.04
FINAL DO, MG/L	12.92	6.44	0.80	2.17	6.44	0.80
DO DEFICIT						
INITIAL, MG/L	3.30	0.37	0.0	4.32	0.37	0.0
FINAL, MG/L	-3.65	6.44	0.80	10.02	6.44	0.80
RIVER DISCHARGE						
INITIAL, CFS	5.67	0.37	0.0	5.67	0.37	0.0
FINAL, CFS	9.61	6.44	0.80	9.61	6.44	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	70.55	0.37	0.0	67.66	0.37	0.0
FINAL, DEG F	63.08	6.44	0.80	42.26	6.44	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	85.60	0.37	0.0	85.60	0.37	0.0
FINAL BOD, MG/L	10.78	6.44	0.80	19.23	6.44	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.11	0.37	0.0	0.11	0.37	0.0
FINAL BOD IN RIVER	4.76	6.44	0.80	6.47	6.44	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	23.58	0.37	0.0	23.58	0.37	0.0
FINAL BOD, MG/L	9.28	6.44	0.80	12.34	6.44	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	114.01	0.37	0.0	115.74	0.37	0.0
FINAL VALUE, MG/L	24.82	6.44	0.80	38.05	6.44	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	25.86	0.37	0.0	25.86	0.37	0.0
FINAL VALUE, MG/L	10.17	6.44	0.80	13.53	6.44	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.17	0.37	0.0	3.17	0.37	0.0
FINAL VALUE, MG/L	1.20	6.44	0.80	1.20	6.44	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	9.38	0.37	0.0	9.38	0.37	0.0
FINAL VALUE, MG/L	4.51	6.44	0.80	5.14	6.44	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	85.54	0.37	0.0	85.54	0.37	0.0
FINAL PERCENT	0.68	6.44	0.80	4.14	6.44	0.80



OCT.20-30 RUN. SK.R.
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
MILES DOWNSTREAM



OCT.20-30 RUN. SK.R.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
(x10¹)
0.00
2.50
5.00
7.50
10.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
MILES DOWNSTREAM

H. Simulation Results for January, Week 3, 1967

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.20	51.00	75.00	0.0	25.00	0.080	0.0	20.50	9.50	29.00	100.00	0.0	0.0	0.87	0.40

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	10.00	0.180	0.0	3.80	5.00	0.50	0.10	40.00	1.00	0.50	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.12	0.23	25.00	25.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.200	1.000	0.300	1.790

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.50	1.50	3.00	0.50	4.00	0.400	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

GAMMA1 = 0.87 , GAMMA2 = 0.40
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 1.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 4.95 CFS, RIVER Q = 0.12 CFS, TOTAL Q = 5.07 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 0.50 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		0.1	12.79	9.95		3.80
0.0	0.37	50.6	50.6	50.6	5.1	8.20	8.13	8.17	20.10
0.02	0.50	48.5	48.5	48.5	5.1	7.10	7.25	7.18	19.88
0.04	0.63	46.7	46.7	46.7	5.1	6.35	6.44	6.39	19.66
0.06	0.76	45.1	45.1	45.1	5.2	5.88	5.93	5.91	19.46
0.08	0.90	43.7	43.7	43.7	5.2	5.63	5.65	5.64	19.27
0.10	1.03	42.4	42.4	42.4	5.2	5.53	5.53	5.53	19.09
0.12	1.16	41.3	41.3	41.3	5.3	5.55	5.52	5.53	18.91
0.14	1.29	40.3	40.3	40.3	5.3	5.64	5.60	5.62	18.74
0.16	1.43	39.4	39.4	39.4	5.3	5.79	5.75	5.77	18.58
0.18	1.56	38.6	38.6	38.6	5.3	5.99	5.93	5.96	18.42
0.20	1.70	37.9	37.9	37.9	5.4	6.20	6.14	6.17	18.26
0.22	1.83	37.2	37.2	37.2	5.4	6.44	6.38	6.41	18.11
0.24	1.96	36.7	36.7	36.7	5.4	6.69	6.62	6.65	17.96
0.26	2.10	36.2	36.2	36.2	5.5	6.93	6.87	6.90	17.82
0.28	2.23	35.7	35.7	35.7	5.5	7.18	7.12	7.15	17.67
0.30	2.37	35.3	35.3	35.3	5.5	7.43	7.36	7.40	17.53
0.32	2.50	34.9	34.9	34.9	5.6	7.67	7.60	7.64	17.40
0.34	2.64	34.6	34.6	34.6	5.6	7.90	7.84	7.87	17.26
0.36	2.78	34.3	34.3	34.3	5.6	8.13	8.06	8.10	17.13
0.38	2.91	34.1	34.1	34.1	5.7	8.34	8.28	8.31	17.00
0.40	3.05	33.9	33.9	33.9	5.7	8.55	8.49	8.52	16.87
0.42	3.19	33.7	33.7	33.7	5.7	8.75	8.69	8.72	16.75
0.44	3.32	33.5	33.5	33.5	5.8	8.94	8.88	8.91	16.63
0.46	3.46	33.3	33.3	33.3	5.8	9.12	9.06	9.09	16.50
0.48	3.60	33.2	33.2	33.2	5.8	9.29	9.23	9.26	16.38
0.50	3.74	33.0	33.0	33.0	5.8	9.45	9.40	9.42	16.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	3.88	32.9	32.9	32.9	5.9	9.60	9.55	9.57	16.15
0.54	4.01	32.8	32.8	32.8	5.9	9.74	9.70	9.72	16.03
0.56	4.15	32.7	32.7	32.7	5.9	9.88	9.83	9.86	15.91
0.58	4.29	32.7	32.7	32.7	6.0	10.01	9.96	9.99	15.80
0.60	4.43	32.6	32.6	32.6	6.0	10.13	10.09	10.11	15.69
0.62	4.57	32.5	32.5	32.5	6.0	10.24	10.20	10.22	15.58
0.64	4.71	32.5	32.5	32.5	6.1	10.35	10.31	10.33	15.47
0.66	4.85	32.4	32.4	32.4	6.1	10.00	9.96	9.98	15.36
0.68	4.99	32.4	32.4	32.4	6.1	9.67	9.63	9.65	15.25
0.70	5.13	32.3	32.3	32.3	6.2	9.35	9.31	9.33	15.15
0.72	5.27	32.3	32.3	32.3	6.2	9.05	9.00	9.03	15.04
0.74	5.42	32.3	32.3	32.3	6.2	8.76	8.71	8.74	14.94
0.76	5.56	32.2	32.2	32.2	6.3	8.49	8.43	8.46	14.84
0.78	5.70	32.2	32.2	32.2	6.3	8.23	8.17	8.20	14.74
0.80	5.84	32.2	32.2	32.2	6.3	7.98	7.92	7.95	14.64
0.82	5.98	32.2	32.2	32.2	6.4	7.74	7.68	7.71	14.54
0.84	6.13	32.1	32.1	32.1	6.4	7.51	7.45	7.48	14.44
0.86	6.27	32.1	32.1	32.1	6.4	7.29	7.23	7.26	14.34
0.88	6.41	32.1	32.1	32.1	6.5	7.09	7.02	7.06	14.25
0.90	6.56	32.1	32.1	32.1	6.5	6.89	6.83	6.86	14.15
0.92	6.70	32.1	32.1	32.1	6.5	6.70	6.64	6.67	14.06
0.94	6.85	32.1	32.1	32.1	6.6	6.52	6.46	6.49	13.96
0.96	6.99	32.1	32.1	32.1	6.6	6.35	6.29	6.32	13.87
0.98	7.13	32.1	32.1	32.1	6.6	6.19	6.13	6.16	13.78
1.00	7.28	32.1	32.1	32.1	6.7	6.04	5.97	6.00	13.69
1.02	7.42	32.1	32.1	32.1	6.7	5.89	5.82	5.86	13.60

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	7.57	32.0	32.0	32.0	6.7	5.75	5.68	5.72	13.51
1.06	7.72	32.0	32.0	32.0	6.8	5.62	5.55	5.58	13.42
1.08	7.86	32.0	32.0	32.0	6.8	5.49	5.42	5.46	13.33
1.10	8.01	32.0	32.0	32.0	6.8	5.37	5.30	5.34	13.25
1.12	8.16	32.0	32.0	32.0	6.9	5.26	5.19	5.22	13.16
1.14	8.30	32.0	32.0	32.0	6.9	5.15	5.08	5.11	13.08
1.16	8.45	32.0	32.0	32.0	6.9	5.04	4.98	5.01	12.99
1.18	8.60	32.0	32.0	32.0	7.0	4.94	4.88	4.91	12.91
1.20	8.74	32.0	32.0	32.0	7.0	4.85	4.78	4.82	12.83
1.22	8.89	32.0	32.0	32.0	7.0	4.76	4.70	4.73	12.75
1.24	9.04	32.0	32.0	32.0	7.1	4.68	4.61	4.65	12.67
1.26	9.19	32.0	32.0	32.0	7.1	4.60	4.53	4.57	12.59
1.28	9.34	32.0	32.0	32.0	7.1	4.52	4.46	4.49	12.51
1.30	9.49	32.0	32.0	32.0	7.2	4.45	4.39	4.42	12.43
1.32	9.64	32.0	32.0	32.0	7.2	4.38	4.32	4.35	12.35
1.34	9.79	32.0	32.0	32.0	7.2	4.32	4.26	4.29	12.27
1.36	9.94	32.0	32.0	32.0	7.3	4.26	4.19	4.23	12.20
1.38	10.09	32.0	32.0	32.0	7.3	4.20	4.14	4.17	12.12
1.40	10.24	32.0	32.0	32.0	7.3	4.15	4.08	4.12	12.05
1.42	10.39	32.0	32.0	32.0	7.4	4.10	4.03	4.06	11.97
1.44	10.54	32.0	32.0	32.0	7.4	4.05	3.99	4.02	11.90
1.46	10.69	32.0	32.0	32.0	7.4	4.00	3.94	3.97	11.83
1.48	10.84	32.0	32.0	32.0	7.5	3.96	3.90	3.93	11.75
1.50	10.99	32.0	32.0	32.0	7.5	3.92	3.86	3.89	11.68
1.52	11.14	32.0	32.0	32.0	7.6	3.88	3.82	3.85	11.61
1.54	11.30	32.0	32.0	32.0	7.6	3.84	3.79	3.82	11.54

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	11.45	32.0	32.0	32.0	7.6	3.81	3.75	3.78	11.47
1.58	11.60	32.0	32.0	32.0	7.7	3.78	3.72	3.75	11.40
1.60	11.76	32.0	32.0	32.0	7.7	3.75	3.69	3.72	11.33
1.62	11.91	32.0	32.0	32.0	7.7	3.72	3.67	3.70	11.27
1.64	12.06	32.0	32.0	32.0	7.8	3.70	3.64	3.67	11.20
1.66	12.22	32.0	32.0	32.0	7.8	3.67	3.62	3.65	11.13
1.68	12.37	32.0	32.0	32.0	7.8	3.65	3.60	3.62	11.07
1.70	12.52	32.0	32.0	32.0	7.9	3.63	3.58	3.60	11.00
1.72	12.68	32.0	32.0	32.0	7.9	3.61	3.56	3.59	10.94
1.74	12.83	32.0	32.0	32.0	7.9	3.59	3.54	3.57	10.87
1.76	12.99	32.0	32.0	32.0	8.0	3.58	3.53	3.55	10.81
1.78	13.14	32.0	32.0	32.0	8.0	3.56	3.51	3.54	10.74
1.80	13.30	32.0	32.0	32.0	8.0	3.55	3.50	3.52	10.68
1.82	13.46	32.0	32.0	32.0	8.1	3.53	3.49	3.51	10.62
1.84	13.61	32.0	32.0	32.0	8.1	3.52	3.47	3.50	10.56
1.86	13.77	32.0	32.0	32.0	8.2	3.51	3.46	3.49	10.50
1.88	13.93	32.0	32.0	32.0	8.2	3.50	3.45	3.48	10.44
1.90	14.08	32.0	32.0	32.0	8.2	3.49	3.45	3.47	10.38
1.92	14.24	32.0	32.0	32.0	8.3	3.48	3.44	3.46	10.32
1.94	14.40	32.0	32.0	32.0	8.3	3.48	3.43	3.45	10.26
1.96	14.55	32.0	32.0	32.0	8.3	3.47	3.42	3.45	10.20
1.98	14.71	32.0	32.0	32.0	8.4	3.46	3.42	3.44	10.14

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	9.96	2.78	12.37	3.47	15.84	5.00	0.50	0.10
0.0	0.37	35.54	2.69	38.23	18.34	56.56	9.39	28.33	97.64
0.02	0.50	33.64	2.73	36.38	18.13	54.51	9.17	28.00	90.10
0.04	0.63	31.71	2.77	34.47	17.93	52.41	8.95	27.69	83.50
0.06	0.76	29.97	2.80	32.77	17.75	50.52	8.75	27.38	77.64
0.08	0.90	28.39	2.85	31.24	17.57	48.81	8.57	27.09	72.41
0.10	1.03	26.96	2.89	29.85	17.41	47.26	8.39	26.81	67.70
0.12	1.16	25.64	2.94	28.58	17.25	45.83	8.22	26.53	63.44
0.14	1.29	24.43	2.99	27.42	17.09	44.51	8.06	26.27	59.56
0.16	1.43	23.31	3.04	26.35	16.94	43.29	7.91	26.00	56.00
0.18	1.56	22.26	3.09	25.36	16.79	42.15	7.76	25.75	52.73
0.20	1.70	21.29	3.15	24.43	16.65	41.09	7.62	25.50	49.71
0.22	1.83	20.37	3.20	23.58	16.51	40.09	7.49	25.25	46.92
0.24	1.96	19.52	3.25	22.77	16.38	39.15	7.36	25.01	44.32
0.26	2.10	18.71	3.31	22.02	16.25	38.26	7.24	24.77	41.90
0.28	2.23	17.95	3.36	21.31	16.12	37.43	7.11	24.54	39.65
0.30	2.37	17.23	3.42	20.64	15.99	36.63	7.00	24.31	37.53
0.32	2.50	16.54	3.47	20.01	15.87	35.88	6.88	24.09	35.55
0.34	2.64	15.89	3.52	19.41	15.74	35.16	6.77	23.87	33.70
0.36	2.78	15.28	3.57	18.85	15.62	34.48	6.67	23.65	31.95
0.38	2.91	14.69	3.62	18.32	15.51	33.82	6.56	23.43	30.31
0.40	3.05	14.13	3.67	17.81	15.39	33.20	6.46	23.22	28.76
0.42	3.19	13.60	3.72	17.32	15.28	32.60	6.36	23.01	27.30
0.44	3.32	13.09	3.77	16.86	15.16	32.03	6.27	22.80	25.92
0.46	3.46	12.61	3.82	16.43	15.05	31.48	6.17	22.60	24.61
0.48	3.60	12.14	3.87	16.01	14.94	30.95	6.08	22.40	23.38
0.50	3.74	11.70	3.91	15.61	14.83	30.44	5.99	22.20	22.21

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	3.88	11.27	3.96	15.23	14.72	29.96	5.91	22.00	21.11
0.54	4.01	10.86	4.00	14.87	14.62	29.49	5.82	21.81	20.06
0.56	4.15	10.47	4.05	14.52	14.51	29.03	5.74	21.62	19.07
0.58	4.29	10.10	4.09	14.19	14.41	28.60	5.66	21.43	18.13
0.60	4.43	9.74	4.13	13.87	14.31	28.18	5.58	21.24	17.24
0.62	4.57	9.39	4.17	13.57	14.21	27.77	5.50	21.06	16.39
0.64	4.71	9.06	4.22	13.27	14.11	27.38	5.43	20.87	15.59
0.66	4.85	8.74	4.25	13.00	14.01	27.00	5.35	20.69	14.82
0.68	4.99	8.43	4.29	12.73	13.91	26.64	5.28	20.52	14.10
0.70	5.13	8.14	4.33	12.47	13.82	26.29	5.21	20.34	13.41
0.72	5.27	7.86	4.37	12.22	13.72	25.95	5.14	20.16	12.76
0.74	5.42	7.58	4.40	11.99	13.63	25.61	5.07	19.99	12.14
0.76	5.56	7.32	4.44	11.76	13.53	25.29	5.01	19.82	11.55
0.78	5.70	7.07	4.47	11.54	13.44	24.98	5.00	19.65	10.99
0.80	5.84	6.83	4.51	11.34	13.35	24.68	5.00	19.48	10.46
0.82	5.98	6.59	4.54	11.14	13.26	24.39	5.00	19.32	9.95
0.84	6.13	6.37	4.57	10.94	13.17	24.11	5.00	19.16	9.47
0.86	6.27	6.15	4.61	10.76	13.08	23.84	5.00	18.99	9.01
0.88	6.41	5.94	4.64	10.58	12.99	23.57	5.00	18.83	8.57
0.90	6.56	5.74	4.67	10.41	12.90	23.32	5.00	18.68	8.16
0.92	6.70	5.55	4.70	10.25	12.82	23.07	5.00	18.52	7.77
0.94	6.85	5.36	4.73	10.09	12.73	22.82	5.00	18.36	7.39
0.96	6.99	5.18	4.76	9.94	12.65	22.59	5.00	18.21	7.04
0.98	7.13	5.01	4.78	9.79	12.57	22.36	5.00	18.06	6.70
1.00	7.28	4.84	4.81	9.65	12.48	22.14	5.00	17.91	6.37
1.02	7.42	4.68	4.84	9.52	12.40	21.92	5.00	17.76	6.07

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN- STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND- ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG- ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	7.57	4.52	4.87	9.39	12.32	21.71	5.00	17.61	5.78
1.06	7.72	4.37	4.89	9.26	12.24	21.50	5.00	17.47	5.50
1.08	7.86	4.23	4.92	9.15	12.16	21.31	5.00	17.32	5.23
1.10	8.01	4.09	4.94	9.03	12.08	21.11	5.00	17.18	4.98
1.12	8.16	3.95	4.97	8.92	12.00	20.92	5.00	17.04	4.74
1.14	8.30	3.82	4.99	8.81	11.93	20.74	5.00	16.90	4.52
1.16	8.45	3.70	5.01	8.71	11.85	20.56	5.00	16.76	4.30
1.18	8.60	3.58	5.04	8.61	11.77	20.39	5.00	16.62	4.09
1.20	8.74	3.46	5.06	8.52	11.70	20.22	5.00	16.49	3.90
1.22	8.89	3.35	5.08	8.43	11.62	20.05	5.00	16.35	3.71
1.24	9.04	3.24	5.10	8.34	11.55	19.89	5.00	16.22	3.53
1.26	9.19	3.13	5.13	8.26	11.48	19.74	5.00	16.09	3.36
1.28	9.34	3.03	5.15	8.18	11.41	19.58	5.00	15.96	3.20
1.30	9.49	2.93	5.17	8.10	11.33	19.43	5.00	15.83	3.05
1.32	9.64	2.84	5.19	8.02	11.26	19.29	5.00	15.70	2.91
1.34	9.79	2.75	5.21	7.95	11.19	19.15	5.00	15.57	2.77
1.36	9.94	2.66	5.23	7.88	11.12	19.01	5.00	15.45	2.63
1.38	10.09	2.57	5.25	7.82	11.05	18.87	5.00	15.33	2.51
1.40	10.24	2.49	5.27	7.75	10.99	18.74	5.00	15.20	2.39
1.42	10.39	2.41	5.28	7.69	10.92	18.61	5.00	15.08	2.28
1.44	10.54	2.33	5.30	7.63	10.85	18.48	5.00	14.96	2.17
1.46	10.69	2.26	5.32	7.58	10.78	18.36	5.00	14.84	2.06
1.48	10.84	2.18	5.34	7.52	10.72	18.24	5.00	14.72	1.97
1.50	10.99	2.11	5.36	7.47	10.65	18.12	5.00	14.61	1.87
1.52	11.14	2.05	5.37	7.42	10.59	18.01	5.00	14.49	1.78
1.54	11.30	1.98	5.39	7.37	10.52	17.90	5.00	14.38	1.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

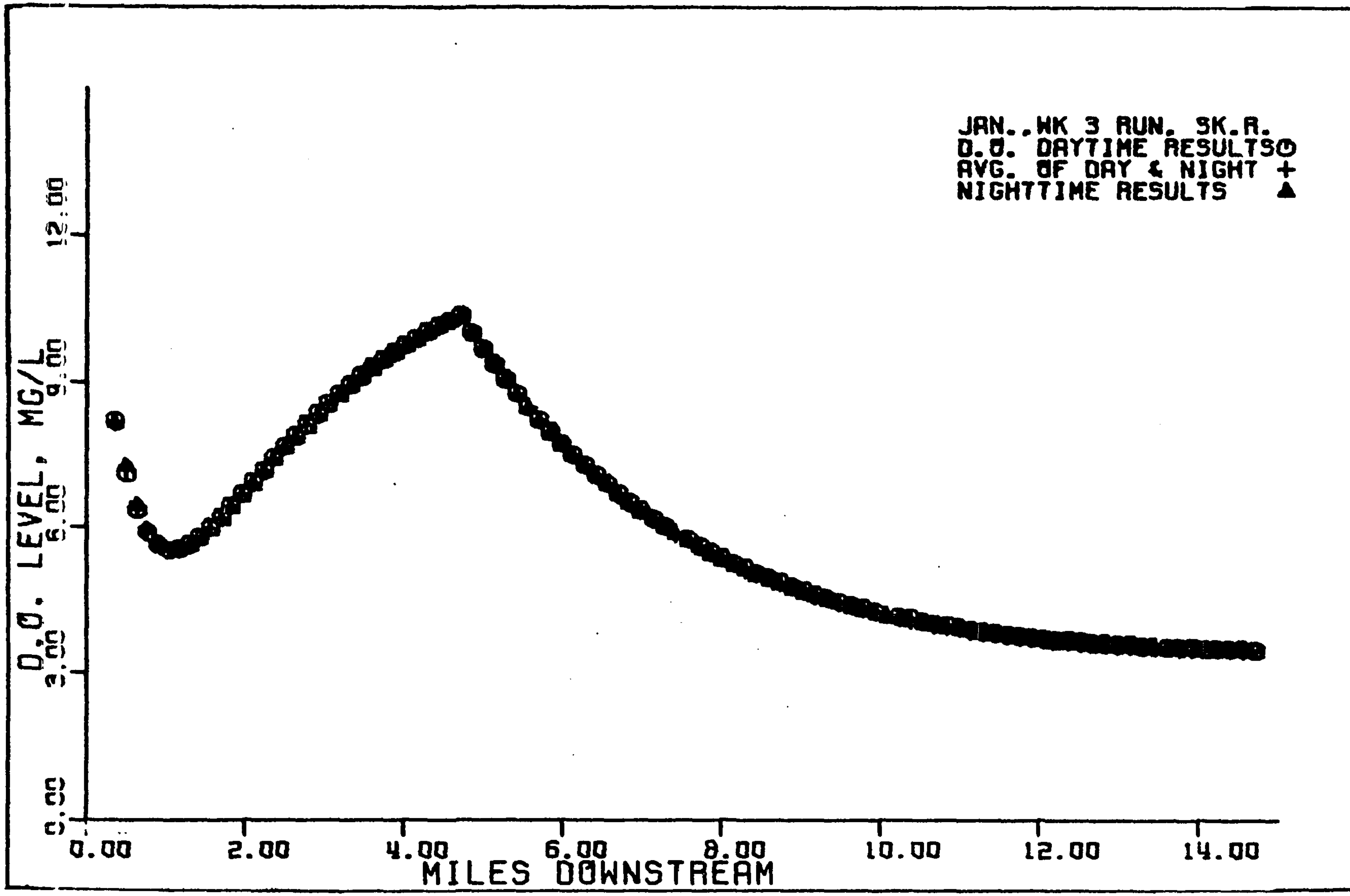
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	11.45	1.92	5.41	7.33	10.46	17.79	5.00	14.26	1.62
1.58	11.60	1.86	5.42	7.28	10.40	17.68	5.00	14.15	1.54
1.60	11.76	1.80	5.44	7.24	10.34	17.57	5.00	14.04	1.47
1.62	11.91	1.74	5.45	7.20	10.27	17.47	5.00	13.93	1.40
1.64	12.06	1.69	5.47	7.16	10.21	17.37	5.00	13.82	1.33
1.66	12.22	1.63	5.49	7.12	10.15	17.27	5.00	13.71	1.27
1.68	12.37	1.58	5.50	7.08	10.09	17.18	5.00	13.60	1.21
1.70	12.52	1.53	5.52	7.05	10.03	17.08	5.00	13.50	1.15
1.72	12.68	1.49	5.53	7.02	9.97	16.99	5.00	13.39	1.10
1.74	12.83	1.44	5.55	6.98	9.91	16.90	5.00	13.29	1.05
1.76	12.99	1.39	5.56	6.95	9.86	16.81	5.00	13.19	1.00
1.78	13.14	1.35	5.57	6.92	9.80	16.72	5.00	13.08	0.95
1.80	13.30	1.31	5.59	6.90	9.74	16.64	5.00	12.98	0.90
1.82	13.46	1.27	5.60	6.87	9.69	16.55	5.00	12.88	0.86
1.84	13.61	1.23	5.62	6.84	9.63	16.47	5.00	12.78	0.82
1.86	13.77	1.19	5.63	6.82	9.57	16.39	5.00	12.68	0.78
1.88	13.93	1.15	5.64	6.79	9.52	16.31	5.00	12.59	0.75
1.90	14.08	1.12	5.66	6.77	9.46	16.24	5.00	12.49	0.71
1.92	14.24	1.08	5.67	6.75	9.41	16.16	5.00	12.40	0.68
1.94	14.40	1.05	5.68	6.73	9.36	16.09	5.00	12.30	0.65
1.96	14.55	1.02	5.69	6.71	9.30	16.01	5.00	12.21	0.62
1.98	14.71	0.98	5.71	6.69	9.25	15.94	5.00	12.11	0.59

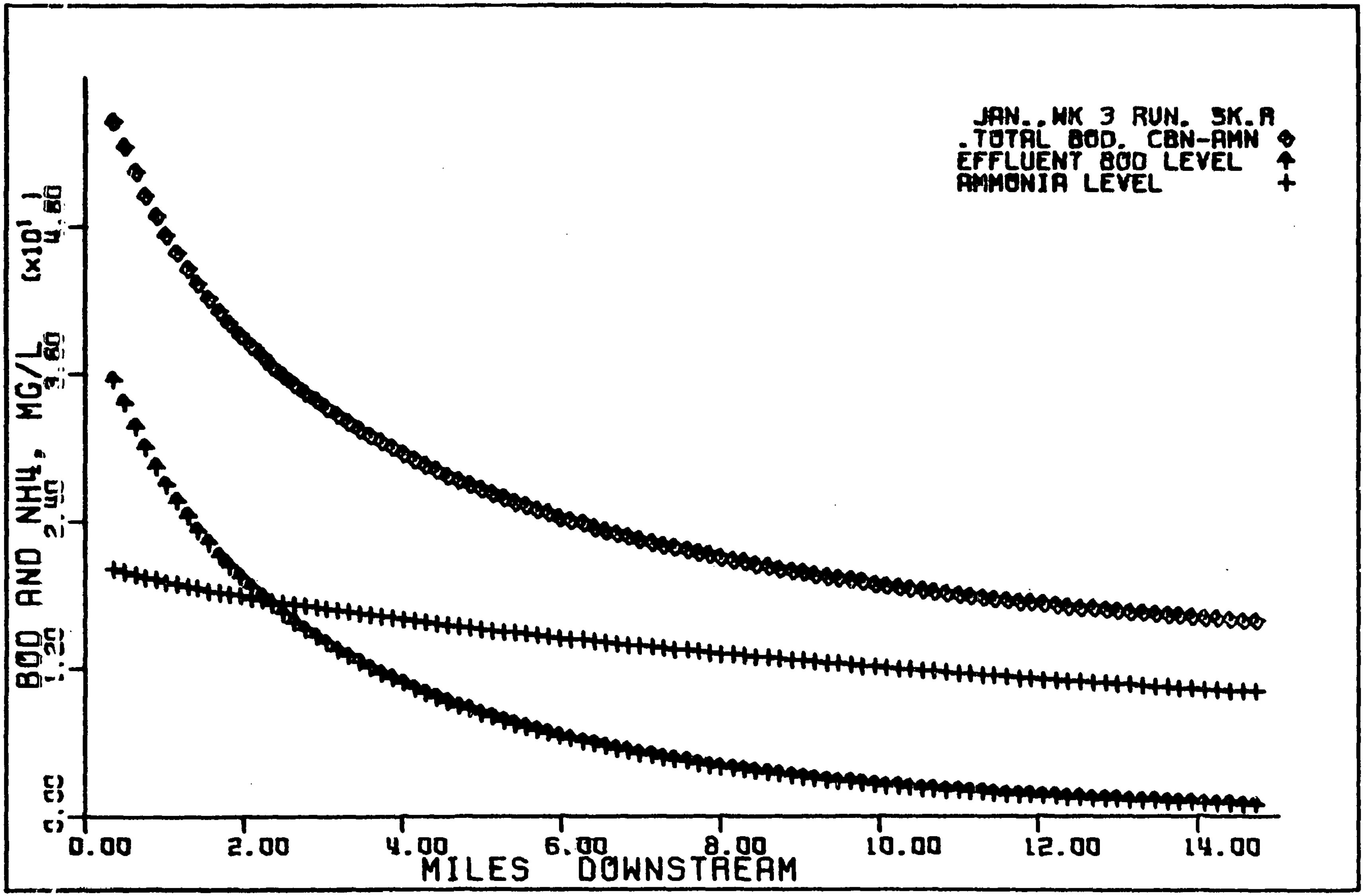
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.20	0.37	0.0	8.13	0.37	0.0
MINIMUM DO, MG/L	3.46	14.71	1.98	3.42	14.71	1.98
FINAL DO, MG/L	7.98	5.84	0.80	7.92	5.84	0.80
DO DEFICIT						
INITIAL, MG/L	2.65	0.37	0.0	2.72	0.37	0.0
FINAL, MG/L	6.20	5.84	0.80	6.25	5.84	0.80
RIVER DISCHARGE						
INITIAL, CFS	5.07	0.37	0.0	5.07	0.37	0.0
FINAL, CFS	6.33	5.84	0.80	6.33	5.84	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	50.55	0.37	0.0	50.55	0.37	0.0
FINAL, DEG F	32.19	5.84	0.80	32.19	5.84	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	35.54	0.37	0.0	35.54	0.37	0.0
FINAL BOD, MG/L	6.80	5.84	0.80	6.85	5.84	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.19	0.37	0.0	0.19	0.37	0.0
FINAL BOD IN RIVER	4.46	5.84	0.80	4.56	5.84	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	18.34	0.37	0.0	18.34	0.37	0.0
FINAL BOD, MG/L	13.35	5.84	0.80	13.35	5.84	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	56.29	0.37	0.0	56.83	0.37	0.0
FINAL VALUE, MG/L	24.61	5.84	0.80	24.76	5.84	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	20.10	0.37	0.0	20.10	0.37	0.0
FINAL VALUE, MG/L	14.64	5.84	0.80	14.64	5.84	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	9.39	0.37	0.0	9.39	0.37	0.0
FINAL VALUE, MG/L	5.00	5.84	0.80	5.00	5.84	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	28.33	0.37	0.0	28.33	0.37	0.0
FINAL VALUE, MG/L	19.48	5.84	0.80	19.48	5.84	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	97.64	0.37	0.0	97.64	0.37	0.0
FINAL PERCENT	10.46	5.84	0.80	10.46	5.84	0.80


JAN.,WK 3 RUN, SK.R.
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


JAN., WK 3 RUN. 5K.A
.TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10¹)
MILES DOWNSTREAM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00

I. Simulation Results for January, Week 4, 1967

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.30	55.00	75.00	0.0	45.00	0.080	0.0	25.00	9.50	29.00	100.00	0.0	0.0	0.78	0.40

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	78.00	75.00	2.00	0.130	0.0	3.00	5.00	0.50	0.10	40.00	1.00	0.50	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.50	0.20	25.00	25.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.200	1.000	0.200	2.120

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.50	1.50	3.00	0.50	4.00	0.400	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                  AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
     RUN IDENT :  BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
     SEASON : WINTER

 GAMMA1 =    0.78 , GAMMA2 =    0.40
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES



IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    5.11 CFS, RIVER Q =    0.50 CFS, TOTAL Q =    5.61 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =    0.50 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
```

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		0.5	11.09	10.66		3.00
0.0	0.37	52.9	52.9	52.9	5.6	7.98	7.94	7.96	23.04
0.02	0.51	50.7	50.7	50.7	5.6	5.73	6.20	5.97	22.83
0.04	0.64	48.6	48.6	48.6	5.7	4.18	4.51	4.35	22.64
0.06	0.78	46.8	46.8	46.8	5.7	3.22	3.43	3.32	22.45
0.08	0.92	45.2	45.2	45.2	5.7	2.66	2.79	2.73	22.27
0.10	1.05	43.8	43.8	43.8	5.7	2.40	2.46	2.43	22.11
0.12	1.19	42.5	42.5	42.5	5.8	2.34	2.36	2.35	21.94
0.14	1.33	41.4	41.4	41.4	5.8	2.43	2.42	2.43	21.78
0.16	1.47	40.3	40.3	40.3	5.8	2.63	2.59	2.61	21.63
0.18	1.60	39.4	39.4	39.4	5.9	2.90	2.84	2.87	21.48
0.20	1.74	38.6	38.6	38.6	5.9	3.22	3.14	3.18	21.34
0.22	1.88	37.9	37.9	37.9	5.9	3.57	3.48	3.52	21.20
0.24	2.02	37.3	37.3	37.3	5.9	3.94	3.84	3.89	21.06
0.26	2.16	36.7	36.7	36.7	6.0	4.31	4.21	4.26	20.92
0.28	2.30	36.2	36.2	36.2	6.0	4.69	4.58	4.64	20.79
0.30	2.44	35.7	35.7	35.7	6.0	5.06	4.95	5.01	20.66
0.32	2.58	35.3	35.3	35.3	6.1	5.42	5.32	5.37	20.53
0.34	2.72	35.0	35.0	35.0	6.1	5.78	5.67	5.73	20.40
0.36	2.86	34.6	34.6	34.6	6.1	6.12	6.02	6.07	20.27
0.38	3.00	34.4	34.4	34.4	6.1	6.45	6.35	6.40	20.15
0.40	3.14	34.1	34.1	34.1	6.2	6.76	6.66	6.71	20.03
0.42	3.28	33.9	33.9	33.9	6.2	7.06	6.96	7.01	19.91
0.44	3.42	33.7	33.7	33.7	6.2	7.34	7.25	7.30	19.79
0.46	3.57	33.5	33.5	33.5	6.2	7.61	7.53	7.57	19.67
0.48	3.71	33.3	33.3	33.3	6.3	7.87	7.79	7.83	19.55
0.50	3.85	33.2	33.2	33.2	6.3	8.11	8.03	8.07	19.44

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967, WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	3.99	33.1	33.1	33.1	6.3	8.34	8.26	8.30	19.32
0.54	4.13	32.9	32.9	32.9	6.4	8.56	8.48	8.52	19.21
0.56	4.28	32.8	32.8	32.8	6.4	8.76	8.69	8.73	19.10
0.58	4.42	32.7	32.7	32.7	6.4	8.96	8.89	8.92	18.99
0.60	4.56	32.7	32.7	32.7	6.4	9.14	9.07	9.10	18.88
0.62	4.71	32.6	32.6	32.6	6.5	9.31	9.25	9.28	18.77
0.64	4.85	32.5	32.5	32.5	6.5	9.47	9.41	9.44	18.66
0.66	4.99	32.5	32.5	32.5	6.5	9.62	9.57	9.60	18.56
0.68	5.14	32.4	32.4	32.4	6.6	9.23	9.17	9.20	18.45
0.70	5.28	32.4	32.4	32.4	6.6	8.86	8.79	8.82	18.35
0.72	5.43	32.3	32.3	32.3	6.6	8.50	8.43	8.47	18.24
0.74	5.57	32.3	32.3	32.3	6.6	8.17	8.09	8.13	18.14
0.76	5.72	32.3	32.3	32.3	6.7	7.85	7.77	7.81	18.04
0.78	5.86	32.2	32.2	32.2	6.7	7.55	7.47	7.51	17.94
0.80	6.01	32.2	32.2	32.2	6.7	7.26	7.18	7.22	17.84
0.82	6.15	32.2	32.2	32.2	6.8	6.99	6.91	6.95	17.74
0.84	6.30	32.2	32.2	32.2	6.8	6.74	6.65	6.69	17.64
0.86	6.45	32.1	32.1	32.1	6.8	6.49	6.40	6.45	17.54
0.88	6.59	32.1	32.1	32.1	6.9	6.26	6.17	6.22	17.44
0.90	6.74	32.1	32.1	32.1	6.9	6.04	5.95	6.00	17.35
0.92	6.89	32.1	32.1	32.1	6.9	5.84	5.74	5.79	17.25
0.94	7.03	32.1	32.1	32.1	6.9	5.64	5.55	5.59	17.16
0.96	7.18	32.1	32.1	32.1	7.0	5.46	5.36	5.41	17.06
0.98	7.33	32.1	32.1	32.1	7.0	5.28	5.18	5.23	16.97
1.00	7.48	32.1	32.1	32.1	7.0	5.12	5.02	5.07	16.88
1.02	7.63	32.1	32.1	32.1	7.1	4.96	4.86	4.91	16.79

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	7.77	32.1	32.1	32.1	7.1	4.81	4.71	4.76	16.70
1.06	7.92	32.0	32.0	32.0	7.1	4.67	4.57	4.62	16.61
1.08	8.07	32.0	32.0	32.0	7.1	4.54	4.44	4.49	16.52
1.10	8.22	32.0	32.0	32.0	7.2	4.41	4.32	4.36	16.43
1.12	8.37	32.0	32.0	32.0	7.2	4.30	4.20	4.25	16.34
1.14	8.52	32.0	32.0	32.0	7.2	4.19	4.09	4.14	16.25
1.16	8.67	32.0	32.0	32.0	7.3	4.08	3.98	4.03	16.17
1.18	8.82	32.0	32.0	32.0	7.3	3.98	3.89	3.93	16.08
1.20	8.97	32.0	32.0	32.0	7.3	3.89	3.79	3.84	16.00
1.22	9.12	32.0	32.0	32.0	7.4	3.80	3.71	3.75	15.91
1.24	9.27	32.0	32.0	32.0	7.4	3.72	3.62	3.67	15.83
1.26	9.42	32.0	32.0	32.0	7.4	3.64	3.55	3.60	15.74
1.28	9.57	32.0	32.0	32.0	7.4	3.57	3.48	3.52	15.66
1.30	9.73	32.0	32.0	32.0	7.5	3.50	3.41	3.46	15.58
1.32	9.88	32.0	32.0	32.0	7.5	3.44	3.35	3.39	15.50
1.34	10.03	32.0	32.0	32.0	7.5	3.38	3.29	3.34	15.42
1.36	10.18	32.0	32.0	32.0	7.6	3.33	3.23	3.28	15.34
1.38	10.33	32.0	32.0	32.0	7.6	3.28	3.18	3.23	15.26
1.40	10.49	32.0	32.0	32.0	7.6	3.23	3.14	3.18	15.18
1.42	10.64	32.0	32.0	32.0	7.7	3.18	3.09	3.14	15.10
1.44	10.79	32.0	32.0	32.0	7.7	3.14	3.05	3.10	15.02
1.46	10.95	32.0	32.0	32.0	7.7	3.10	3.01	3.06	14.94
1.48	11.10	32.0	32.0	32.0	7.8	3.07	2.98	3.02	14.87
1.50	11.25	32.0	32.0	32.0	7.8	3.03	2.95	2.99	14.79
1.52	11.41	32.0	32.0	32.0	7.8	3.00	2.92	2.96	14.72
1.54	11.56	32.0	32.0	32.0	7.8	2.98	2.89	2.93	14.64

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967, WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	11.72	32.0	32.0	32.0	7.9	2.95	2.87	2.91	14.57
1.58	11.87	32.0	32.0	32.0	7.9	2.93	2.85	2.89	14.49
1.60	12.03	32.0	32.0	32.0	7.9	2.91	2.82	2.87	14.42
1.62	12.18	32.0	32.0	32.0	8.0	2.89	2.81	2.85	14.35
1.64	12.34	32.0	32.0	32.0	8.0	2.87	2.79	2.83	14.27
1.66	12.49	32.0	32.0	32.0	8.0	2.85	2.78	2.81	14.20
1.68	12.65	32.0	32.0	32.0	8.1	2.84	2.76	2.80	14.13
1.70	12.80	32.0	32.0	32.0	8.1	2.83	2.75	2.79	14.06
1.72	12.96	32.0	32.0	32.0	8.1	2.82	2.74	2.78	13.99
1.74	13.12	32.0	32.0	32.0	8.2	2.81	2.73	2.77	13.92
1.76	13.27	32.0	32.0	32.0	8.2	2.80	2.72	2.76	13.85
1.78	13.43	32.0	32.0	32.0	8.2	2.79	2.72	2.75	13.78
1.80	13.59	32.0	32.0	32.0	8.3	2.78	2.71	2.75	13.71
1.82	13.74	32.0	32.0	32.0	8.3	2.78	2.71	2.74	13.65
1.84	13.90	32.0	32.0	32.0	8.3	2.77	2.71	2.74	13.58
1.86	14.06	32.0	32.0	32.0	8.3	2.77	2.70	2.74	13.51
1.88	14.22	32.0	32.0	32.0	8.4	2.77	2.70	2.74	13.45
1.90	14.38	32.0	32.0	32.0	8.4	2.77	2.70	2.73	13.38
1.92	14.53	32.0	32.0	32.0	8.4	2.77	2.70	2.73	13.32
1.94	14.69	32.0	32.0	32.0	8.5	2.77	2.70	2.73	13.25
1.96	14.85	32.0	32.0	32.0	8.5	2.77	2.70	2.73	13.19
1.98	15.01	32.0	32.0	32.0	8.5	2.77	2.70	2.74	13.12

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.01	2.50	3.96	2.74	6.70	5.00	0.50	0.10
0.0	0.37	53.33	2.22	55.55	21.01	76.56	9.10	26.46	91.09
0.02	0.51	49.94	2.26	52.20	20.82	73.02	8.86	26.17	83.72
0.04	0.64	46.50	2.28	48.79	20.64	69.43	8.64	25.90	77.33
0.06	0.78	43.48	2.31	45.80	20.48	66.27	8.43	25.64	71.72
0.08	0.92	40.80	2.35	43.15	20.31	63.46	8.24	25.38	66.75
0.10	1.05	38.39	2.39	40.79	20.16	60.95	8.06	25.14	62.31
0.12	1.19	36.22	2.44	38.66	20.01	58.67	7.89	24.90	58.32
0.14	1.33	34.25	2.48	36.73	19.87	56.60	7.73	24.67	54.69
0.16	1.47	32.44	2.53	34.98	19.73	54.71	7.57	24.45	51.39
0.18	1.60	30.78	2.59	33.37	19.59	52.96	7.43	24.23	48.37
0.20	1.74	29.25	2.64	31.89	19.46	51.35	7.29	24.02	45.59
0.22	1.88	27.83	2.69	30.52	19.33	49.85	7.15	23.81	43.02
0.24	2.02	26.51	2.74	29.25	19.20	48.45	7.03	23.60	40.64
0.26	2.16	25.27	2.80	28.07	19.08	47.15	6.90	23.40	38.43
0.28	2.30	24.12	2.85	26.97	18.96	45.92	6.78	23.20	36.37
0.30	2.44	23.03	2.90	25.93	18.84	44.77	6.67	23.01	34.45
0.32	2.58	22.01	2.95	24.97	18.72	43.69	6.56	22.81	32.64
0.34	2.72	21.05	3.01	24.06	18.60	42.66	6.45	22.62	30.95
0.36	2.86	20.14	3.06	23.20	18.49	41.69	6.35	22.44	29.36
0.38	3.00	19.29	3.11	22.39	18.38	40.77	6.24	22.25	27.87
0.40	3.14	18.47	3.16	21.63	18.27	39.90	6.15	22.07	26.46
0.42	3.28	17.70	3.21	20.91	18.16	39.07	6.05	21.89	25.13
0.44	3.42	16.97	3.26	20.23	18.05	38.27	5.96	21.72	23.88
0.46	3.57	16.27	3.31	19.58	17.94	37.52	5.86	21.54	22.69
0.48	3.71	15.61	3.35	18.97	17.83	36.80	5.78	21.37	21.57
0.50	3.85	14.98	3.40	18.38	17.73	36.11	5.69	21.20	20.51

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	3.99	14.38	3.44	17.83	17.62	35.45	5.61	21.03	19.50
0.54	4.13	13.81	3.49	17.30	17.52	34.82	5.52	20.86	18.55
0.56	4.28	13.26	3.53	16.80	17.42	34.21	5.44	20.70	17.65
0.58	4.42	12.74	3.58	16.32	17.32	33.63	5.36	20.54	16.79
0.60	4.56	12.24	3.62	15.86	17.22	33.08	5.29	20.37	15.97
0.62	4.71	11.76	3.66	15.42	17.12	32.54	5.21	20.21	15.20
0.64	4.85	11.31	3.70	15.01	17.02	32.03	5.14	20.06	14.47
0.66	4.99	10.87	3.74	14.61	16.92	31.54	5.07	19.90	13.77
0.68	5.14	10.45	3.78	14.23	16.83	31.06	5.00	19.75	13.11
0.70	5.28	10.05	3.82	13.87	16.73	30.60	5.00	19.59	12.48
0.72	5.43	9.67	3.85	13.52	16.64	30.16	5.00	19.44	11.88
0.74	5.57	9.30	3.89	13.19	16.54	29.74	5.00	19.29	11.31
0.76	5.72	8.95	3.93	12.88	16.45	29.33	5.00	19.14	10.77
0.78	5.86	8.61	3.96	12.58	16.36	28.93	5.00	18.99	10.26
0.80	6.01	8.29	4.00	12.29	16.27	28.55	5.00	18.85	9.77
0.82	6.15	7.98	4.03	12.01	16.18	28.19	5.00	18.70	9.30
0.84	6.30	7.68	4.06	11.74	16.09	27.83	5.00	18.56	8.86
0.86	6.45	7.40	4.09	11.49	16.00	27.49	5.00	18.42	8.44
0.88	6.59	7.12	4.13	11.25	15.91	27.16	5.00	18.28	8.04
0.90	6.74	6.86	4.16	11.01	15.82	26.84	5.00	18.14	7.66
0.92	6.89	6.60	4.19	10.79	15.73	26.53	5.00	18.00	7.29
0.94	7.03	6.36	4.22	10.58	15.65	26.23	5.00	17.86	6.95
0.96	7.18	6.13	4.25	10.37	15.56	25.94	5.00	17.73	6.62
0.98	7.33	5.90	4.27	10.18	15.48	25.66	5.00	17.59	6.30
1.00	7.48	5.69	4.30	9.99	15.39	25.38	5.00	17.46	6.00
1.02	7.63	5.48	4.33	9.81	15.31	25.12	5.00	17.33	5.72

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	7.77	5.28	4.36	9.64	15.23	24.86	5.00	17.20	5.45
1.06	7.92	5.09	4.38	9.47	15.15	24.62	5.00	17.07	5.19
1.08	8.07	4.91	4.41	9.31	15.06	24.38	5.00	16.94	4.95
1.10	8.22	4.73	4.43	9.16	14.98	24.14	5.00	16.82	4.71
1.12	8.37	4.56	4.46	9.02	14.90	23.92	5.00	16.69	4.49
1.14	8.52	4.39	4.48	8.88	14.82	23.70	5.00	16.56	4.28
1.16	8.67	4.24	4.51	8.74	14.74	23.49	5.00	16.44	4.07
1.18	8.82	4.08	4.53	8.61	14.67	23.28	5.00	16.32	3.88
1.20	8.97	3.94	4.55	8.49	14.59	23.08	5.00	16.20	3.70
1.22	9.12	3.80	4.57	8.37	14.51	22.88	5.00	16.08	3.52
1.24	9.27	3.66	4.60	8.26	14.43	22.69	5.00	15.96	3.36
1.26	9.42	3.53	4.62	8.15	14.36	22.51	5.00	15.84	3.20
1.28	9.57	3.41	4.64	8.05	14.28	22.33	5.00	15.72	3.05
1.30	9.73	3.29	4.66	7.95	14.21	22.15	5.00	15.61	2.91
1.32	9.88	3.17	4.68	7.85	14.13	21.98	5.00	15.49	2.77
1.34	10.03	3.06	4.70	7.76	14.06	21.82	5.00	15.38	2.64
1.36	10.18	2.95	4.72	7.67	13.99	21.66	5.00	15.27	2.51
1.38	10.33	2.85	4.74	7.59	13.91	21.50	5.00	15.15	2.40
1.40	10.49	2.75	4.76	7.51	13.84	21.35	5.00	15.04	2.28
1.42	10.64	2.65	4.78	7.43	13.77	21.20	5.00	14.93	2.18
1.44	10.79	2.56	4.80	7.35	13.70	21.05	5.00	14.82	2.07
1.46	10.95	2.47	4.82	7.28	13.63	20.91	5.00	14.72	1.98
1.48	11.10	2.38	4.83	7.22	13.56	20.77	5.00	14.61	1.88
1.50	11.25	2.30	4.85	7.15	13.49	20.64	5.00	14.50	1.80
1.52	11.41	2.22	4.87	7.09	13.42	20.51	5.00	14.40	1.71
1.54	11.56	2.14	4.89	7.03	13.35	20.38	5.00	14.29	1.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

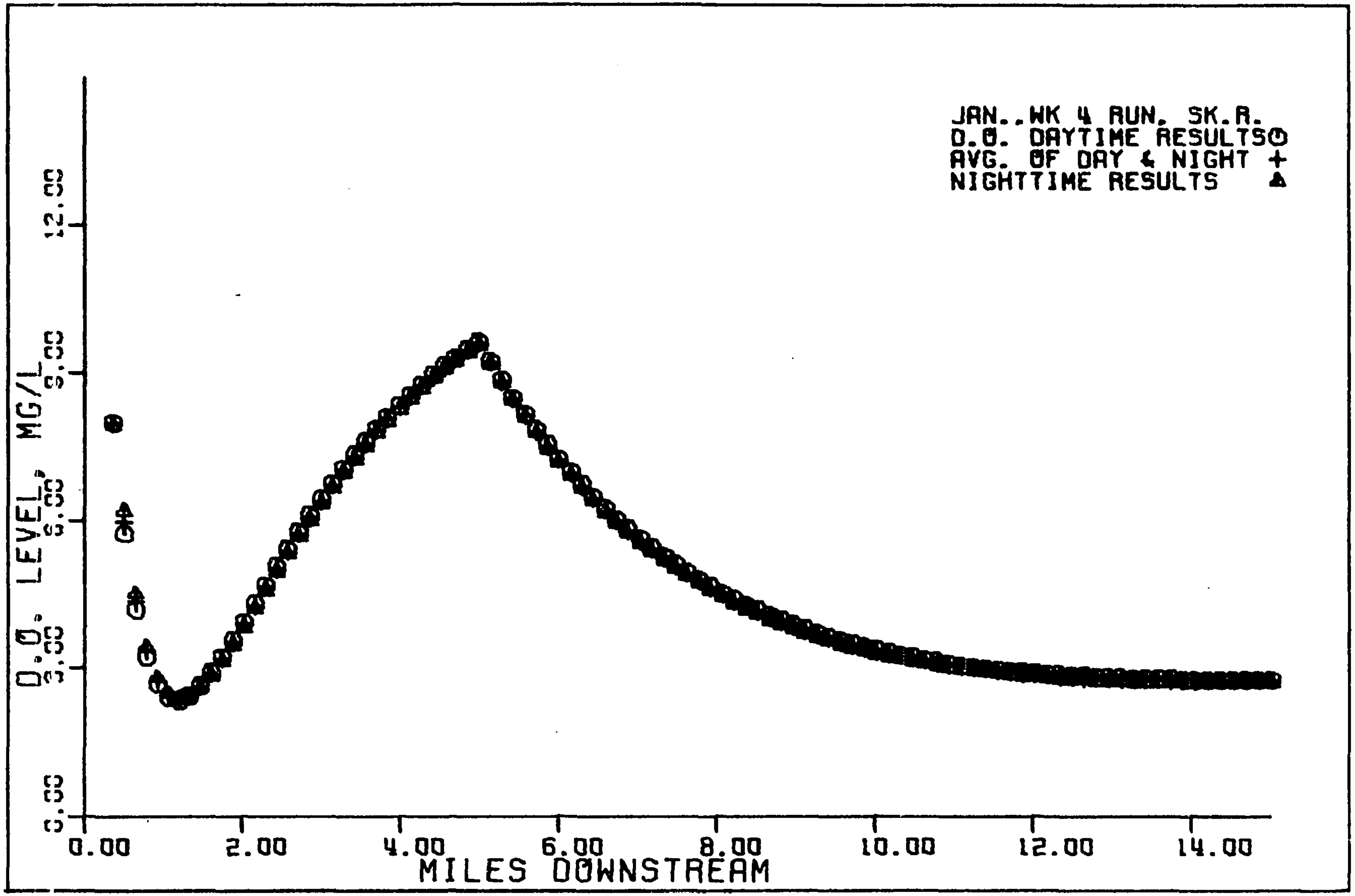
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	11.72	2.07	4.90	6.97	13.28	20.25	5.00	14.19	1.55
1.58	11.87	1.99	4.92	6.92	13.22	20.13	5.00	14.09	1.48
1.60	12.03	1.93	4.94	6.86	13.15	20.01	5.00	13.98	1.41
1.62	12.18	1.86	4.95	6.81	13.08	19.90	5.00	13.88	1.35
1.64	12.34	1.79	4.97	6.76	13.02	19.78	5.00	13.78	1.28
1.66	12.49	1.73	4.99	6.72	12.95	19.67	5.00	13.69	1.22
1.68	12.65	1.67	5.00	6.67	12.89	19.56	5.00	13.59	1.17
1.70	12.80	1.61	5.02	6.63	12.82	19.45	5.00	13.49	1.11
1.72	12.96	1.56	5.03	6.59	12.76	19.35	5.00	13.39	1.06
1.74	13.12	1.51	5.05	6.55	12.70	19.25	5.00	13.30	1.01
1.76	13.27	1.45	5.06	6.52	12.63	19.15	5.00	13.20	0.96
1.78	13.43	1.40	5.08	6.48	12.57	19.05	5.00	13.11	0.92
1.80	13.59	1.36	5.09	6.45	12.51	18.95	5.00	13.01	0.88
1.82	13.74	1.31	5.10	6.41	12.45	18.86	5.00	12.92	0.83
1.84	13.90	1.27	5.12	6.38	12.38	18.77	5.00	12.83	0.80
1.86	14.06	1.22	5.13	6.35	12.32	18.68	5.00	12.74	0.76
1.88	14.22	1.18	5.15	6.33	12.26	18.59	5.00	12.65	0.72
1.90	14.38	1.14	5.16	6.30	12.20	18.50	5.00	12.56	0.69
1.92	14.53	1.10	5.17	6.27	12.14	18.42	5.00	12.47	0.66
1.94	14.69	1.06	5.19	6.25	12.08	18.34	5.00	12.38	0.63
1.96	14.85	1.03	5.20	6.23	12.03	18.25	5.00	12.30	0.60
1.98	15.01	0.99	5.21	6.21	11.97	18.17	5.00	12.21	0.57

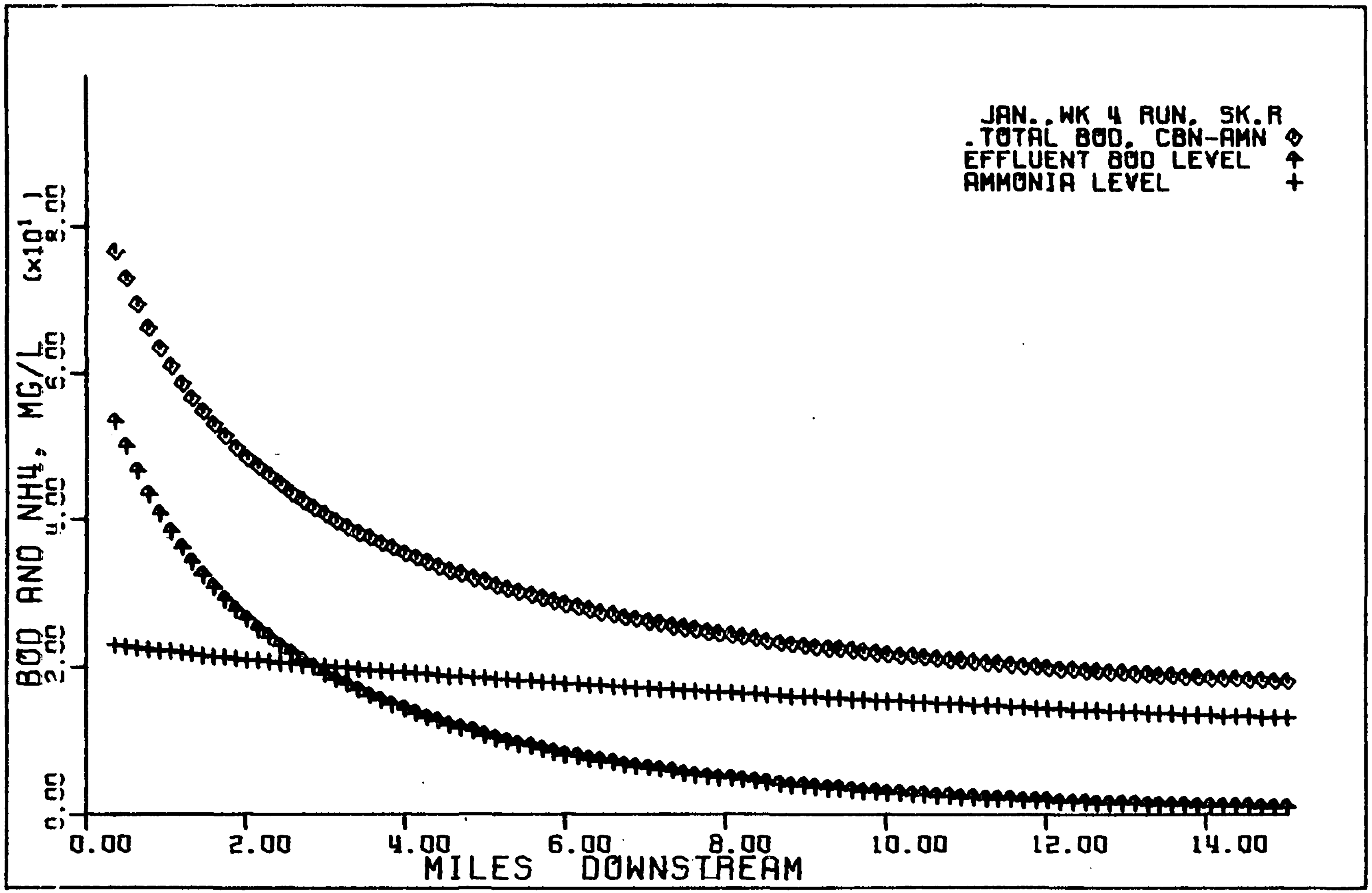
WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	7.98	0.37	0.0	7.94	0.37	0.0
MINIMUM DO, MG/L	2.34	1.19	0.12	2.36	1.19	0.12
FINAL DO, MG/L	7.26	6.01	0.80	7.18	6.01	0.80
DO DEFICIT						
INITIAL, MG/L	2.53	0.37	0.0	2.57	0.37	0.0
FINAL, MG/L	6.90	6.01	0.80	6.99	6.01	0.80
RIVER DISCHARGE						
INITIAL, CFS	5.61	0.37	0.0	5.61	0.37	0.0
FINAL, CFS	6.74	6.01	0.80	6.74	6.01	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	52.95	0.37	0.0	52.95	0.37	0.0
FINAL, DEG F	32.21	6.01	0.80	32.21	6.01	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	53.33	0.37	0.0	53.33	0.37	0.0
FINAL BOD, MG/L	8.24	6.01	0.80	8.34	6.01	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.18	0.37	0.0	0.18	0.37	0.0
FINAL BOD IN RIVER	3.95	6.01	0.80	4.04	6.01	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	21.01	0.37	0.0	21.01	0.37	0.0
FINAL BOD, MG/L	16.27	6.01	0.80	16.27	6.01	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	76.29	0.37	0.0	76.83	0.37	0.0
FINAL VALUE, MG/L	28.46	6.01	0.80	28.64	6.01	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	23.04	0.37	0.0	23.04	0.37	0.0
FINAL VALUE, MG/L	17.84	6.01	0.80	17.84	6.01	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	9.10	0.37	0.0	9.10	0.37	0.0
FINAL VALUE, MG/L	5.00	6.01	0.80	5.00	6.01	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	26.46	0.37	0.0	26.46	0.37	0.0
FINAL VALUE, MG/L	18.85	6.01	0.80	18.85	6.01	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	91.09	0.37	0.0	91.09	0.37	0.0
FINAL PERCENT	9.77	6.01	0.80	9.77	6.01	0.80


JAN..WK 4 RUN. SK.R.
D.O. DAYTIME RESULTS ⊙
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS ▲
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


JAN..WK 4 RUN. SK.R
.TOTAL BOD. CBN-AMN ◇
EFFLUENT BOD LEVEL ↑
AMMONIA LEVEL +
BOD AND NH4, MG/L (x10^1)
0.00
2.00
4.00
6.00
8.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

J. Additional Analysis of Winter Conditions,

Reduced Reaeration, January, Week 3, 1967

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.20	51.00	75.00	0.0	25.00	0.080	0.0	20.50	9.50	29.00	100.00	0.0	0.0	0.87	0.40

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	10.00	0.180	0.0	3.80	5.00	0.50	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.12	0.23	25.00	25.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.200	1.000	0.300	1.790

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMP	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.50	1.50	3.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

      INPUT DATA FOR THIS ANALYSIS

      STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
      RUN IDENT :  BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
      SEASON : WINTER

 GAMMA1 =    0.87 , GAMMA2 =    0.40
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   4.95 CFS, RIVER Q =   0.12 CFS, TOTAL Q =   5.07 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.50 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TC COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		0.1	12.79	9.95		3.80
0.0	0.37	50.6	50.6	50.6	5.1	8.20	8.13	8.17	20.10
0.02	0.50	48.5	48.5	48.5	5.1	7.68	7.72	7.70	19.88
0.04	0.63	46.7	46.7	46.7	5.1	7.35	7.37	7.36	19.66
0.06	0.76	45.1	45.1	45.1	5.2	7.19	7.20	7.19	19.46
0.08	0.90	43.7	43.7	43.7	5.2	7.15	7.14	7.15	19.27
0.10	1.03	42.4	42.4	42.4	5.2	7.19	7.18	7.19	19.09
0.12	1.16	41.3	41.3	41.3	5.3	7.30	7.28	7.29	18.91
0.14	1.29	40.3	40.3	40.3	5.3	7.45	7.42	7.43	18.74
0.16	1.43	39.4	39.4	39.4	5.3	7.63	7.59	7.61	18.58
0.18	1.56	38.6	38.6	38.6	5.3	7.82	7.79	7.80	18.42
0.20	1.70	37.9	37.9	37.9	5.4	8.03	7.99	8.01	18.26
0.22	1.83	37.2	37.2	37.2	5.4	8.24	8.20	8.22	18.11
0.24	1.96	36.7	36.7	36.7	5.4	8.45	8.42	8.43	17.96
0.26	2.10	36.2	36.2	36.2	5.5	8.66	8.63	8.65	17.82
0.28	2.23	35.7	35.7	35.7	5.5	8.87	8.83	8.85	17.67
0.30	2.37	35.3	35.3	35.3	5.5	9.07	9.04	9.05	17.53
0.32	2.50	34.9	34.9	34.9	5.6	9.27	9.23	9.25	17.40
0.34	2.64	34.6	34.6	34.6	5.6	9.45	9.42	9.44	17.26
0.36	2.78	34.3	34.3	34.3	5.6	9.63	9.60	9.62	17.13
0.38	2.91	34.1	34.1	34.1	5.7	9.80	9.77	9.79	17.00
0.40	3.05	33.9	33.9	33.9	5.7	9.97	9.93	9.95	16.87
0.42	3.19	33.7	33.7	33.7	5.7	10.12	10.09	10.10	16.75
0.44	3.32	33.5	33.5	33.5	5.8	10.26	10.24	10.25	16.63
0.46	3.46	33.3	33.3	33.3	5.8	10.40	10.37	10.39	16.50
0.48	3.60	33.2	33.2	33.2	5.8	10.53	10.50	10.52	16.38
0.50	3.74	33.0	33.0	33.0	5.8	10.65	10.63	10.64	16.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	3.88	32.9	32.9	32.9	5.9	10.77	10.74	10.76	16.15
0.54	4.01	32.8	32.8	32.8	5.9	10.88	10.85	10.86	16.03
0.56	4.15	32.7	32.7	32.7	5.9	10.98	10.96	10.97	15.91
0.58	4.29	32.7	32.7	32.7	6.0	11.07	11.05	11.06	15.80
0.60	4.43	32.6	32.6	32.6	6.0	11.16	11.14	11.15	15.69
0.62	4.57	32.5	32.5	32.5	6.0	11.25	11.23	11.24	15.58
0.64	4.71	32.5	32.5	32.5	6.1	11.33	11.31	11.32	15.47
0.66	4.85	32.4	32.4	32.4	6.1	11.04	11.02	11.03	15.36
0.68	4.99	32.4	32.4	32.4	6.1	10.77	10.75	10.76	15.25
0.70	5.13	32.3	32.3	32.3	6.2	10.50	10.48	10.49	15.15
0.72	5.27	32.3	32.3	32.3	6.2	10.25	10.22	10.23	15.04
0.74	5.42	32.3	32.3	32.3	6.2	10.00	9.97	9.98	14.94
0.76	5.56	32.2	32.2	32.2	6.3	9.75	9.73	9.74	14.84
0.78	5.70	32.2	32.2	32.2	6.3	9.52	9.49	9.51	14.74
0.80	5.84	32.2	32.2	32.2	6.3	9.29	9.26	9.28	14.64
0.82	5.98	32.2	32.2	32.2	6.4	9.07	9.04	9.06	14.54
0.84	6.13	32.1	32.1	32.1	6.4	8.86	8.83	8.84	14.44
0.86	6.27	32.1	32.1	32.1	6.4	8.65	8.62	8.64	14.34
0.88	6.41	32.1	32.1	32.1	6.5	8.45	8.42	8.44	14.25
0.90	6.56	32.1	32.1	32.1	6.5	8.26	8.22	8.24	14.15
0.92	6.70	32.1	32.1	32.1	6.5	8.07	8.04	8.05	14.06
0.94	6.85	32.1	32.1	32.1	6.6	7.89	7.85	7.87	13.96
0.96	6.99	32.1	32.1	32.1	6.6	7.71	7.67	7.69	13.87
0.98	7.13	32.1	32.1	32.1	6.6	7.54	7.50	7.52	13.78
1.00	7.28	32.1	32.1	32.1	6.7	7.37	7.33	7.35	13.69
1.02	7.42	32.1	32.1	32.1	6.7	7.21	7.17	7.19	13.60

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	7.57	32.0	32.0	32.0	6.7	7.05	7.01	7.03	13.51
1.06	7.72	32.0	32.0	32.0	6.8	6.90	6.86	6.88	13.42
1.08	7.86	32.0	32.0	32.0	6.8	6.75	6.71	6.73	13.33
1.10	8.01	32.0	32.0	32.0	6.8	6.60	6.57	6.58	13.25
1.12	8.16	32.0	32.0	32.0	6.9	6.46	6.42	6.44	13.16
1.14	8.30	32.0	32.0	32.0	6.9	6.33	6.29	6.31	13.08
1.16	8.45	32.0	32.0	32.0	6.9	6.19	6.16	6.17	12.99
1.18	8.60	32.0	32.0	32.0	7.0	6.07	6.03	6.05	12.91
1.20	8.74	32.0	32.0	32.0	7.0	5.94	5.90	5.92	12.83
1.22	8.89	32.0	32.0	32.0	7.0	5.82	5.78	5.80	12.75
1.24	9.04	32.0	32.0	32.0	7.1	5.70	5.66	5.68	12.67
1.26	9.19	32.0	32.0	32.0	7.1	5.59	5.55	5.57	12.59
1.28	9.34	32.0	32.0	32.0	7.1	5.47	5.43	5.45	12.51
1.30	9.49	32.0	32.0	32.0	7.2	5.36	5.32	5.34	12.43
1.32	9.64	32.0	32.0	32.0	7.2	5.26	5.22	5.24	12.35
1.34	9.79	32.0	32.0	32.0	7.2	5.16	5.12	5.14	12.27
1.36	9.94	32.0	32.0	32.0	7.3	5.06	5.02	5.04	12.20
1.38	10.09	32.0	32.0	32.0	7.3	4.96	4.92	4.94	12.12
1.40	10.24	32.0	32.0	32.0	7.3	4.86	4.82	4.84	12.05
1.42	10.39	32.0	32.0	32.0	7.4	4.77	4.73	4.75	11.97
1.44	10.54	32.0	32.0	32.0	7.4	4.68	4.64	4.66	11.90
1.46	10.69	32.0	32.0	32.0	7.4	4.59	4.55	4.57	11.83
1.48	10.84	32.0	32.0	32.0	7.5	4.51	4.47	4.49	11.75
1.50	10.99	32.0	32.0	32.0	7.5	4.42	4.39	4.40	11.68
1.52	11.14	32.0	32.0	32.0	7.6	4.34	4.30	4.32	11.61
1.54	11.30	32.0	32.0	32.0	7.6	4.26	4.23	4.25	11.54

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	11.45	32.0	32.0	32.0	7.6	4.19	4.15	4.17	11.47
1.58	11.60	32.0	32.0	32.0	7.7	4.11	4.07	4.09	11.40
1.60	11.76	32.0	32.0	32.0	7.7	4.04	4.00	4.02	11.33
1.62	11.91	32.0	32.0	32.0	7.7	3.97	3.93	3.95	11.27
1.64	12.06	32.0	32.0	32.0	7.8	3.90	3.86	3.88	11.20
1.66	12.22	32.0	32.0	32.0	7.8	3.83	3.79	3.81	11.13
1.68	12.37	32.0	32.0	32.0	7.8	3.77	3.73	3.75	11.07
1.70	12.52	32.0	32.0	32.0	7.9	3.70	3.66	3.68	11.00
1.72	12.68	32.0	32.0	32.0	7.9	3.64	3.60	3.62	10.94
1.74	12.83	32.0	32.0	32.0	7.9	3.58	3.54	3.56	10.87
1.76	12.99	32.0	32.0	32.0	8.0	3.52	3.48	3.50	10.81
1.78	13.14	32.0	32.0	32.0	8.0	3.46	3.42	3.44	10.74
1.80	13.30	32.0	32.0	32.0	8.0	3.40	3.37	3.38	10.68
1.82	13.46	32.0	32.0	32.0	8.1	3.35	3.31	3.33	10.62
1.84	13.61	32.0	32.0	32.0	8.1	3.29	3.26	3.27	10.56
1.86	13.77	32.0	32.0	32.0	8.2	3.24	3.20	3.22	10.50
1.88	13.93	32.0	32.0	32.0	8.2	3.19	3.15	3.17	10.44
1.90	14.08	32.0	32.0	32.0	8.2	3.13	3.10	3.12	10.38
1.92	14.24	32.0	32.0	32.0	8.3	3.08	3.05	3.07	10.32
1.94	14.40	32.0	32.0	32.0	8.3	3.04	3.00	3.02	10.26
1.96	14.55	32.0	32.0	32.0	8.3	2.99	2.95	2.97	10.20
1.98	14.71	32.0	32.0	32.0	8.4	2.94	2.91	2.92	10.14

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	9.96	2.42	12.37	3.47	15.84	5.00	0.50	0.10
0.0	0.37	35.54	2.69	38.23	18.34	56.56	9.39	28.33	97.64
0.02	0.50	33.64	2.73	36.38	18.13	54.51	9.17	28.00	90.10
0.04	0.63	31.71	2.77	34.47	17.93	52.41	8.95	27.69	83.50
0.06	0.76	29.97	2.80	32.77	17.75	50.52	8.75	27.38	77.64
0.08	0.90	28.39	2.85	31.24	17.57	48.81	8.57	27.09	72.41
0.10	1.03	26.96	2.89	29.85	17.41	47.26	8.39	26.81	67.70
0.12	1.16	25.64	2.94	28.58	17.25	45.83	8.22	26.53	63.44
0.14	1.29	24.43	2.99	27.42	17.09	44.51	8.06	26.27	59.56
0.16	1.43	23.31	3.04	26.35	16.94	43.29	7.91	26.00	56.00
0.18	1.56	22.26	3.09	25.36	16.79	42.15	7.76	25.75	52.73
0.20	1.70	21.29	3.15	24.43	16.65	41.09	7.62	25.50	49.71
0.22	1.83	20.37	3.20	23.58	16.51	40.09	7.49	25.25	46.92
0.24	1.96	19.52	3.25	22.77	16.38	39.15	7.36	25.01	44.32
0.26	2.10	18.71	3.31	22.02	16.25	38.26	7.24	24.77	41.90
0.28	2.23	17.95	3.36	21.31	16.12	37.43	7.11	24.54	39.65
0.30	2.37	17.23	3.42	20.64	15.99	36.63	7.00	24.31	37.53
0.32	2.50	16.54	3.47	20.01	15.87	35.88	6.88	24.09	35.55
0.34	2.64	15.89	3.52	19.41	15.74	35.16	6.77	23.87	33.70
0.36	2.78	15.28	3.57	18.85	15.62	34.48	6.67	23.65	31.95
0.38	2.91	14.69	3.62	18.32	15.51	33.82	6.56	23.43	30.31
0.40	3.05	14.13	3.67	17.81	15.39	33.20	6.46	23.22	28.76
0.42	3.19	13.60	3.72	17.32	15.28	32.60	6.36	23.01	27.30
0.44	3.32	13.09	3.77	16.86	15.16	32.03	6.27	22.80	25.92
0.46	3.46	12.61	3.82	16.43	15.05	31.48	6.17	22.60	24.61
0.48	3.60	12.14	3.87	16.01	14.94	30.95	6.08	22.40	23.38
0.50	3.74	11.70	3.91	15.61	14.83	30.44	5.99	22.20	22.21

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	3.88	11.27	3.96	15.23	14.72	29.96	5.91	22.00	21.11
0.54	4.01	10.86	4.00	14.87	14.62	29.49	5.82	21.81	20.06
0.56	4.15	10.47	4.05	14.52	14.51	29.03	5.74	21.62	19.07
0.58	4.29	10.10	4.09	14.19	14.41	28.60	5.66	21.43	18.13
0.60	4.43	9.74	4.13	13.87	14.31	28.18	5.58	21.24	17.24
0.62	4.57	9.39	4.17	13.57	14.21	27.77	5.50	21.06	16.39
0.64	4.71	9.06	4.22	13.27	14.11	27.38	5.43	20.87	15.59
0.66	4.85	8.74	4.25	13.00	14.01	27.00	5.35	20.69	14.82
0.68	4.99	8.43	4.29	12.73	13.91	26.64	5.28	20.52	14.10
0.70	5.13	8.14	4.33	12.47	13.82	26.29	5.21	20.34	13.41
0.72	5.27	7.86	4.37	12.22	13.72	25.95	5.14	20.16	12.76
0.74	5.42	7.58	4.40	11.99	13.63	25.61	5.07	19.99	12.14
0.76	5.56	7.32	4.44	11.76	13.53	25.29	5.01	19.82	11.55
0.78	5.70	7.07	4.47	11.54	13.44	24.98	5.00	19.65	10.99
0.80	5.84	6.83	4.51	11.34	13.35	24.68	5.00	19.48	10.46
0.82	5.98	6.59	4.54	11.14	13.26	24.39	5.00	19.32	9.95
0.84	6.13	6.37	4.57	10.94	13.17	24.11	5.00	19.16	9.47
0.86	6.27	6.15	4.61	10.76	13.08	23.84	5.00	18.99	9.01
0.88	6.41	5.94	4.64	10.58	12.99	23.57	5.00	18.83	8.57
0.90	6.56	5.74	4.67	10.41	12.90	23.32	5.00	18.68	8.16
0.92	6.70	5.55	4.70	10.25	12.82	23.07	5.00	18.52	7.77
0.94	6.85	5.36	4.73	10.09	12.73	22.82	5.00	18.36	7.39
0.96	6.99	5.18	4.76	9.94	12.65	22.59	5.00	18.21	7.04
0.98	7.13	5.01	4.78	9.79	12.57	22.36	5.00	18.06	6.70
1.00	7.28	4.84	4.81	9.65	12.48	22.14	5.00	17.91	6.37
1.02	7.42	4.68	4.84	9.52	12.40	21.92	5.00	17.76	6.07

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967, WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	7.57	4.52	4.87	9.39	12.32	21.71	5.00	17.61	5.78
1.06	7.72	4.37	4.89	9.26	12.24	21.50	5.00	17.47	5.50
1.08	7.86	4.23	4.92	9.15	12.16	21.31	5.00	17.32	5.23
1.10	8.01	4.09	4.94	9.03	12.08	21.11	5.00	17.18	4.98
1.12	8.16	3.95	4.97	8.92	12.00	20.92	5.00	17.04	4.74
1.14	8.30	3.82	4.99	8.81	11.93	20.74	5.00	16.90	4.52
1.16	8.45	3.70	5.01	8.71	11.85	20.56	5.00	16.76	4.30
1.18	8.60	3.58	5.04	8.61	11.77	20.39	5.00	16.62	4.09
1.20	8.74	3.46	5.06	8.52	11.70	20.22	5.00	16.49	3.90
1.22	8.89	3.35	5.08	8.43	11.62	20.05	5.00	16.35	3.71
1.24	9.04	3.24	5.10	8.34	11.55	19.89	5.00	16.22	3.53
1.26	9.19	3.13	5.13	8.26	11.48	19.74	5.00	16.09	3.36
1.28	9.34	3.03	5.15	8.18	11.41	19.58	5.00	15.96	3.20
1.30	9.49	2.93	5.17	8.10	11.33	19.43	5.00	15.83	3.05
1.32	9.64	2.84	5.19	8.02	11.26	19.29	5.00	15.70	2.91
1.34	9.79	2.75	5.21	7.95	11.19	19.15	5.00	15.57	2.77
1.36	9.94	2.66	5.23	7.88	11.12	19.01	5.00	15.45	2.63
1.38	10.09	2.57	5.25	7.82	11.05	18.87	5.00	15.33	2.51
1.40	10.24	2.49	5.27	7.75	10.99	18.74	5.00	15.20	2.39
1.42	10.39	2.41	5.28	7.69	10.92	18.61	5.00	15.08	2.28
1.44	10.54	2.33	5.30	7.63	10.85	18.48	5.00	14.96	2.17
1.46	10.69	2.26	5.32	7.58	10.78	18.36	5.00	14.84	2.06
1.48	10.84	2.18	5.34	7.52	10.72	18.24	5.00	14.72	1.97
1.50	10.99	2.11	5.36	7.47	10.65	18.12	5.00	14.61	1.87
1.52	11.14	2.05	5.37	7.42	10.59	18.01	5.00	14.49	1.78
1.54	11.30	1.98	5.39	7.37	10.52	17.90	5.00	14.38	1.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

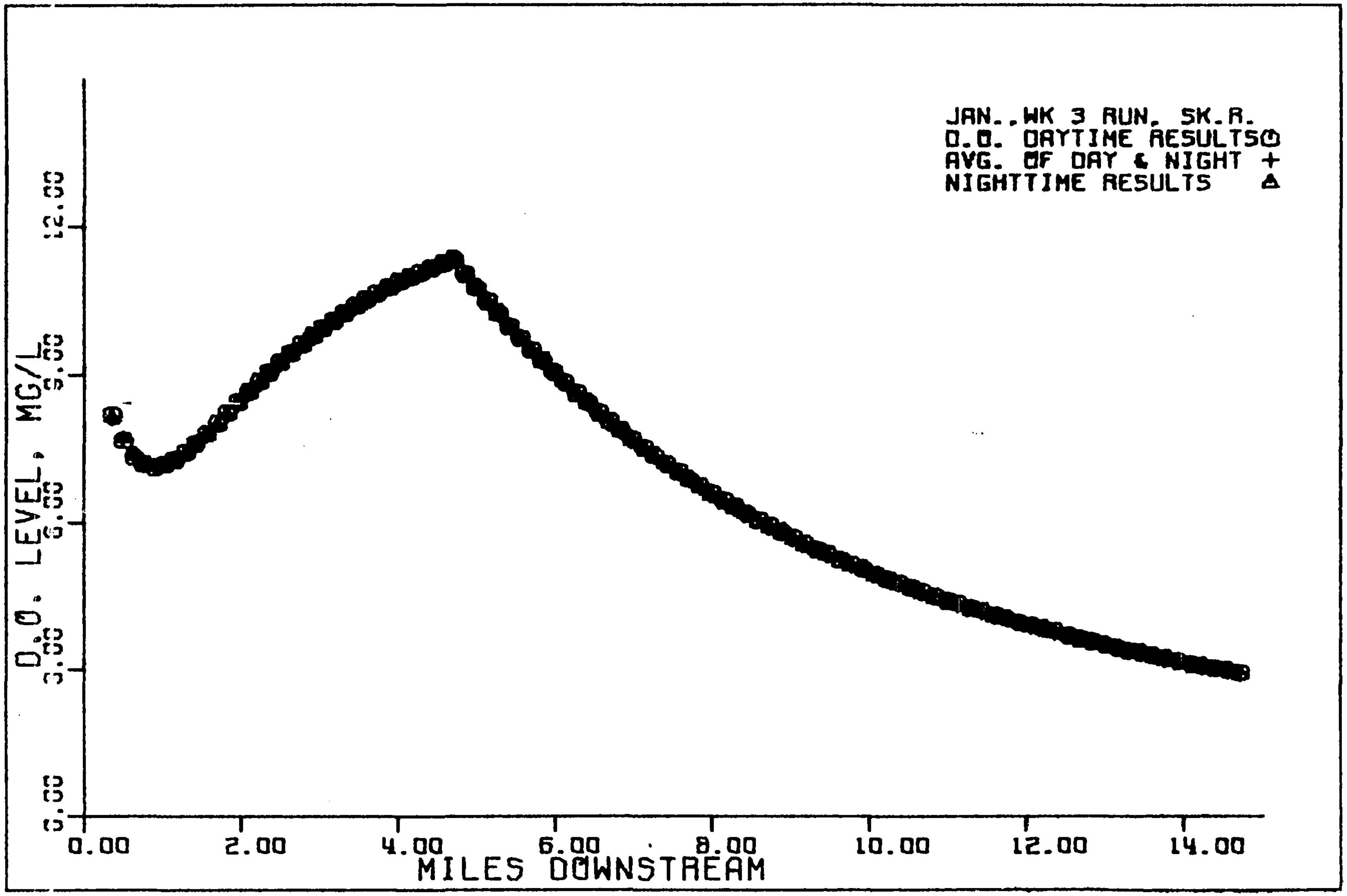
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	11.45	1.92	5.41	7.33	10.46	17.79	5.00	14.26	1.62
1.58	11.60	1.86	5.42	7.28	10.40	17.68	5.00	14.15	1.54
1.60	11.76	1.80	5.44	7.24	10.34	17.57	5.00	14.04	1.47
1.62	11.91	1.74	5.45	7.20	10.27	17.47	5.00	13.93	1.40
1.64	12.06	1.69	5.47	7.16	10.21	17.37	5.00	13.82	1.33
1.66	12.22	1.63	5.49	7.12	10.15	17.27	5.00	13.71	1.27
1.68	12.37	1.58	5.50	7.08	10.09	17.18	5.00	13.60	1.21
1.70	12.52	1.53	5.52	7.05	10.03	17.08	5.00	13.50	1.15
1.72	12.68	1.49	5.53	7.02	9.97	16.99	5.00	13.39	1.10
1.74	12.83	1.44	5.55	6.98	9.91	16.90	5.00	13.29	1.05
1.76	12.99	1.39	5.56	6.95	9.86	16.81	5.00	13.19	1.00
1.78	13.14	1.35	5.57	6.92	9.80	16.72	5.00	13.08	0.95
1.80	13.30	1.31	5.59	6.90	9.74	16.64	5.00	12.98	0.90
1.82	13.46	1.27	5.60	6.87	9.69	16.55	5.00	12.88	0.86
1.84	13.61	1.23	5.62	6.84	9.63	16.47	5.00	12.78	0.82
1.86	13.77	1.19	5.63	6.82	9.57	16.39	5.00	12.68	0.78
1.88	13.93	1.15	5.64	6.79	9.52	16.31	5.00	12.59	0.75
1.90	14.08	1.12	5.66	6.77	9.46	16.24	5.00	12.49	0.71
1.92	14.24	1.08	5.67	6.75	9.41	16.16	5.00	12.40	0.68
1.94	14.40	1.05	5.68	6.73	9.36	16.09	5.00	12.30	0.65
1.96	14.55	1.02	5.69	6.71	9.30	16.01	5.00	12.21	0.62
1.98	14.71	0.98	5.71	6.69	9.25	15.94	5.00	12.11	0.59

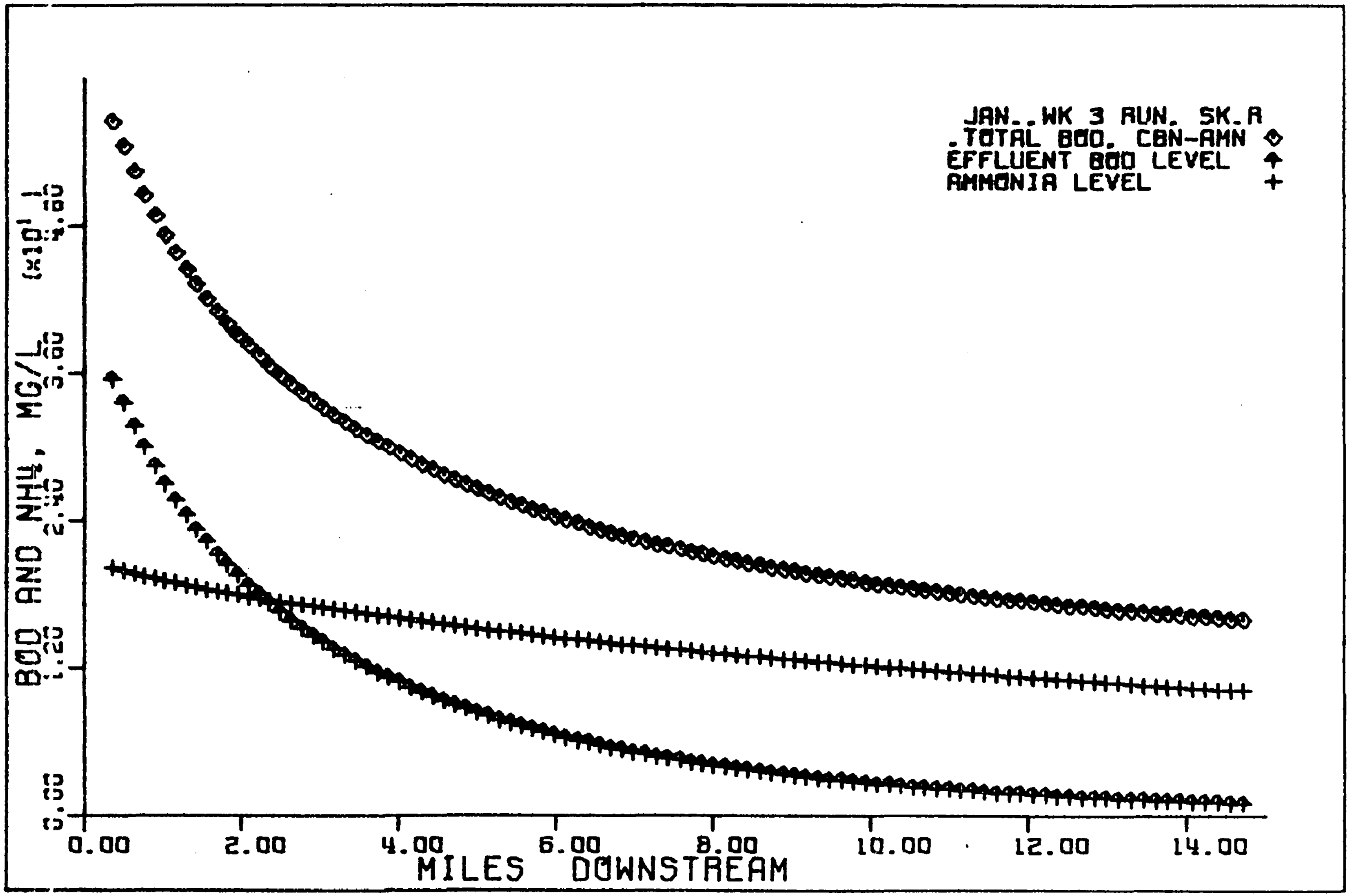
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD DATA FOR JANUARY, 1967,WK 3, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.20	0.37	0.0	8.13	0.37	0.0
MINIMUM DO, MG/L	2.94	14.71	1.98	2.91	14.71	1.98
FINAL DO, MG/L	9.29	5.84	0.80	9.26	5.84	0.80
DO DEFICIT						
INITIAL, MG/L	2.65	0.37	0.0	2.72	0.37	0.0
FINAL, MG/L	4.88	5.84	0.80	4.91	5.84	0.80
RIVER DISCHARGE						
INITIAL, CFS	5.07	0.37	0.0	5.07	0.37	0.0
FINAL, CFS	6.33	5.84	0.80	6.33	5.84	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	50.55	0.37	0.0	50.55	0.37	0.0
FINAL, DEG F	32.19	5.84	0.80	32.19	5.84	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	35.54	0.37	0.0	35.54	0.37	0.0
FINAL BOD, MG/L	6.80	5.84	0.80	6.85	5.84	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.19	0.37	0.0	0.19	0.37	0.0
FINAL BOD IN RIVER	4.46	5.84	0.80	4.56	5.84	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	18.34	0.37	0.0	18.34	0.37	0.0
FINAL BOD, MG/L	13.35	5.84	0.80	13.35	5.84	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	56.29	0.37	0.0	56.83	0.37	0.0
FINAL VALUE, MG/L	24.61	5.84	0.80	24.76	5.84	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	20.10	0.37	0.0	20.10	0.37	0.0
FINAL VALUE, MG/L	14.64	5.84	0.80	14.64	5.84	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	9.39	0.37	0.0	9.39	0.37	0.0
FINAL VALUE, MG/L	5.00	5.84	0.80	5.00	5.84	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	28.33	0.37	0.0	28.33	0.37	0.0
FINAL VALUE, MG/L	19.48	5.84	0.80	19.48	5.84	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	97.64	0.37	0.0	97.64	0.37	0.0
FINAL PERCENT	10.46	5.84	0.80	10.46	5.84	0.80


JAN., WK 3 RUN, SK.R.
D.O. DAYTIME RESULTS ⊙
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM



JAN..WK 3 RUN. SK.A
.TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10¹)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

K. Additional Analysis of Winter Conditions,

Reduced Reaeration, January, Week 4, 1967

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
RUN IDENT : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.30	55.00	75.00	0.0	45.00	0.080	0.0	25.00	9.50	29.00	100.00	0.0	0.0	0.78	0.40

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	78.00	75.00	2.00	0.130	0.0	3.00	5.00	0.50	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.50	0.20	25.00	25.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.200	1.000	0.200	2.120

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.50	1.50	3.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
     RUN IDENT :  BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
     SEASON : WINTER

 GAMMA1 =    0.78 , GAMMA2 =    0.40
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   5.11 CFS, RIVER Q =   0.50 CFS, TOTAL Q =   5.61 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.50 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		0.5	11.09	10.66		3.00
0.0	0.37	52.9	52.9	52.9	5.6	7.98	7.94	7.96	23.04
0.02	0.51	50.7	50.7	50.7	5.6	6.90	7.12	7.01	22.83
0.04	0.64	48.6	48.6	48.6	5.7	6.20	6.35	6.27	22.64
0.06	0.78	46.8	46.8	46.8	5.7	5.80	5.90	5.85	22.45
0.08	0.92	45.2	45.2	45.2	5.7	5.63	5.68	5.65	22.27
0.10	1.05	43.8	43.8	43.8	5.7	5.60	5.63	5.61	22.11
0.12	1.19	42.5	42.5	42.5	5.8	5.68	5.69	5.68	21.94
0.14	1.33	41.4	41.4	41.4	5.8	5.84	5.83	5.83	21.78
0.16	1.47	40.3	40.3	40.3	5.8	6.05	6.02	6.03	21.63
0.18	1.60	39.4	39.4	39.4	5.9	6.29	6.25	6.27	21.48
0.20	1.74	38.6	38.6	38.6	5.9	6.55	6.51	6.53	21.34
0.22	1.88	37.9	37.9	37.9	5.9	6.83	6.78	6.81	21.20
0.24	2.02	37.3	37.3	37.3	5.9	7.11	7.06	7.08	21.06
0.26	2.16	36.7	36.7	36.7	6.0	7.39	7.34	7.36	20.92
0.28	2.30	36.2	36.2	36.2	6.0	7.67	7.61	7.64	20.79
0.30	2.44	35.7	35.7	35.7	6.0	7.94	7.88	7.91	20.66
0.32	2.58	35.3	35.3	35.3	6.1	8.20	8.14	8.17	20.53
0.34	2.72	35.0	35.0	35.0	6.1	8.45	8.39	8.42	20.40
0.36	2.86	34.6	34.6	34.6	6.1	8.69	8.64	8.66	20.27
0.38	3.00	34.4	34.4	34.4	6.1	8.92	8.87	8.89	20.15
0.40	3.14	34.1	34.1	34.1	6.2	9.14	9.09	9.11	20.03
0.42	3.28	33.9	33.9	33.9	6.2	9.34	9.30	9.32	19.91
0.44	3.42	33.7	33.7	33.7	6.2	9.54	9.49	9.52	19.79
0.46	3.57	33.5	33.5	33.5	6.2	9.73	9.68	9.70	19.67
0.48	3.71	33.3	33.3	33.3	6.3	9.90	9.86	9.88	19.55
0.50	3.85	33.2	33.2	33.2	6.3	10.07	10.02	10.05	19.44

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	3.99	33.1	33.1	33.1	6.3	10.22	10.18	10.20	19.32
0.54	4.13	32.9	32.9	32.9	6.4	10.37	10.33	10.35	19.21
0.56	4.28	32.8	32.8	32.8	6.4	10.50	10.47	10.49	19.10
0.58	4.42	32.7	32.7	32.7	6.4	10.63	10.60	10.62	18.99
0.60	4.56	32.7	32.7	32.7	6.4	10.76	10.72	10.74	18.88
0.62	4.71	32.6	32.6	32.6	6.5	10.87	10.84	10.85	18.77
0.64	4.85	32.5	32.5	32.5	6.5	10.98	10.95	10.96	18.66
0.66	4.99	32.5	32.5	32.5	6.5	11.08	11.05	11.06	18.56
0.68	5.14	32.4	32.4	32.4	6.6	10.78	10.75	10.77	18.45
0.70	5.28	32.4	32.4	32.4	6.6	10.50	10.46	10.48	18.35
0.72	5.43	32.3	32.3	32.3	6.6	10.22	10.18	10.20	18.24
0.74	5.57	32.3	32.3	32.3	6.6	9.95	9.92	9.93	18.14
0.76	5.72	32.3	32.3	32.3	6.7	9.70	9.66	9.68	18.04
0.78	5.86	32.2	32.2	32.2	6.7	9.45	9.41	9.43	17.94
0.80	6.01	32.2	32.2	32.2	6.7	9.21	9.17	9.19	17.84
0.82	6.15	32.2	32.2	32.2	6.8	8.98	8.93	8.96	17.74
0.84	6.30	32.2	32.2	32.2	6.8	8.76	8.71	8.73	17.64
0.86	6.45	32.1	32.1	32.1	6.8	8.54	8.49	8.52	17.54
0.88	6.59	32.1	32.1	32.1	6.9	8.33	8.28	8.31	17.44
0.90	6.74	32.1	32.1	32.1	6.9	8.13	8.08	8.11	17.35
0.92	6.89	32.1	32.1	32.1	6.9	7.94	7.89	7.91	17.25
0.94	7.03	32.1	32.1	32.1	6.9	7.75	7.70	7.72	17.16
0.96	7.18	32.1	32.1	32.1	7.0	7.57	7.51	7.54	17.06
0.98	7.33	32.1	32.1	32.1	7.0	7.39	7.34	7.36	16.97
1.00	7.48	32.1	32.1	32.1	7.0	7.22	7.16	7.19	16.88
1.02	7.63	32.1	32.1	32.1	7.1	7.05	7.00	7.03	16.79

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	7.77	32.1	32.1	32.1	7.1	6.89	6.84	6.87	16.70
1.06	7.92	32.0	32.0	32.0	7.1	6.74	6.68	6.71	16.61
1.08	8.07	32.0	32.0	32.0	7.1	6.59	6.53	6.56	16.52
1.10	8.22	32.0	32.0	32.0	7.2	6.44	6.39	6.41	16.43
1.12	8.37	32.0	32.0	32.0	7.2	6.30	6.24	6.27	16.34
1.14	8.52	32.0	32.0	32.0	7.2	6.16	6.11	6.14	16.25
1.16	8.67	32.0	32.0	32.0	7.3	6.03	5.97	6.00	16.17
1.18	8.82	32.0	32.0	32.0	7.3	5.90	5.85	5.87	16.08
1.20	8.97	32.0	32.0	32.0	7.3	5.78	5.72	5.75	16.00
1.22	9.12	32.0	32.0	32.0	7.4	5.66	5.60	5.63	15.91
1.24	9.27	32.0	32.0	32.0	7.4	5.54	5.48	5.51	15.83
1.26	9.42	32.0	32.0	32.0	7.4	5.43	5.37	5.40	15.74
1.28	9.57	32.0	32.0	32.0	7.4	5.32	5.26	5.29	15.66
1.30	9.73	32.0	32.0	32.0	7.5	5.21	5.15	5.18	15.58
1.32	9.88	32.0	32.0	32.0	7.5	5.10	5.05	5.07	15.50
1.34	10.03	32.0	32.0	32.0	7.5	5.00	4.94	4.97	15.42
1.36	10.18	32.0	32.0	32.0	7.6	4.90	4.85	4.87	15.34
1.38	10.33	32.0	32.0	32.0	7.6	4.81	4.75	4.78	15.26
1.40	10.49	32.0	32.0	32.0	7.6	4.72	4.66	4.69	15.18
1.42	10.64	32.0	32.0	32.0	7.7	4.62	4.57	4.60	15.10
1.44	10.79	32.0	32.0	32.0	7.7	4.54	4.48	4.51	15.02
1.46	10.95	32.0	32.0	32.0	7.7	4.45	4.39	4.42	14.94
1.48	11.10	32.0	32.0	32.0	7.8	4.37	4.31	4.34	14.87
1.50	11.25	32.0	32.0	32.0	7.8	4.29	4.23	4.26	14.79
1.52	11.41	32.0	32.0	32.0	7.8	4.21	4.15	4.18	14.72
1.54	11.56	32.0	32.0	32.0	7.8	4.13	4.08	4.10	14.64

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	11.72	32.0	32.0	32.0	7.9	4.06	4.00	4.03	14.57
1.58	11.87	32.0	32.0	32.0	7.9	3.99	3.93	3.96	14.49
1.60	12.03	32.0	32.0	32.0	7.9	3.92	3.86	3.89	14.42
1.62	12.18	32.0	32.0	32.0	8.0	3.85	3.79	3.82	14.35
1.64	12.34	32.0	32.0	32.0	8.0	3.78	3.73	3.75	14.27
1.66	12.49	32.0	32.0	32.0	8.0	3.71	3.66	3.69	14.20
1.68	12.65	32.0	32.0	32.0	8.1	3.65	3.60	3.62	14.13
1.70	12.80	32.0	32.0	32.0	8.1	3.59	3.53	3.56	14.06
1.72	12.96	32.0	32.0	32.0	8.1	3.53	3.47	3.50	13.99
1.74	13.12	32.0	32.0	32.0	8.2	3.47	3.42	3.44	13.92
1.76	13.27	32.0	32.0	32.0	8.2	3.41	3.36	3.38	13.85
1.78	13.43	32.0	32.0	32.0	8.2	3.35	3.30	3.33	13.78
1.80	13.59	32.0	32.0	32.0	8.3	3.30	3.25	3.27	13.71
1.82	13.74	32.0	32.0	32.0	8.3	3.25	3.19	3.22	13.65
1.84	13.90	32.0	32.0	32.0	8.3	3.19	3.14	3.17	13.58
1.86	14.06	32.0	32.0	32.0	8.3	3.14	3.09	3.12	13.51
1.88	14.22	32.0	32.0	32.0	8.4	3.09	3.04	3.07	13.45
1.90	14.38	32.0	32.0	32.0	8.4	3.04	2.99	3.02	13.38
1.92	14.53	32.0	32.0	32.0	8.4	2.99	2.94	2.97	13.32
1.94	14.69	32.0	32.0	32.0	8.5	2.94	2.90	2.92	13.25
1.96	14.85	32.0	32.0	32.0	8.5	2.90	2.85	2.87	13.19
1.98	15.01	32.0	32.0	32.0	8.5	2.85	2.80	2.83	13.12

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.01	1.95	3.96	2.74	6.70	5.00	0.50	0.10
0.0	0.37	53.33	2.22	55.55	21.01	76.56	9.10	26.46	91.09
0.02	0.51	49.94	2.26	52.20	20.82	73.02	8.86	26.17	83.72
0.04	0.64	46.50	2.28	48.79	20.64	69.43	8.64	25.90	77.33
0.06	0.78	43.48	2.31	45.80	20.48	66.27	8.43	25.64	71.72
0.08	0.92	40.80	2.35	43.15	20.31	63.46	8.24	25.38	66.75
0.10	1.05	38.39	2.39	40.79	20.16	60.95	8.06	25.14	62.31
0.12	1.19	36.22	2.44	38.66	20.01	58.67	7.89	24.90	58.32
0.14	1.33	34.25	2.48	36.73	19.87	56.60	7.73	24.67	54.69
0.16	1.47	32.44	2.53	34.98	19.73	54.71	7.57	24.45	51.39
0.18	1.60	30.78	2.59	33.37	19.59	52.96	7.43	24.23	48.37
0.20	1.74	29.25	2.64	31.89	19.46	51.35	7.29	24.02	45.59
0.22	1.88	27.83	2.69	30.52	19.33	49.85	7.15	23.81	43.02
0.24	2.02	26.51	2.74	29.25	19.20	48.45	7.03	23.60	40.64
0.26	2.16	25.27	2.80	28.07	19.08	47.15	6.90	23.40	38.43
0.28	2.30	24.12	2.85	26.97	18.96	45.92	6.78	23.20	36.37
0.30	2.44	23.03	2.90	25.93	18.84	44.77	6.67	23.01	34.45
0.32	2.58	22.01	2.95	24.97	18.72	43.69	6.56	22.81	32.64
0.34	2.72	21.05	3.01	24.06	18.60	42.66	6.45	22.62	30.95
0.36	2.86	20.14	3.06	23.20	18.49	41.69	6.35	22.44	29.36
0.38	3.00	19.29	3.11	22.39	18.38	40.77	6.24	22.25	27.87
0.40	3.14	18.47	3.16	21.63	18.27	39.90	6.15	22.07	26.46
0.42	3.28	17.70	3.21	20.91	18.16	39.07	6.05	21.89	25.13
0.44	3.42	16.97	3.26	20.23	18.05	38.27	5.96	21.72	23.88
0.46	3.57	16.27	3.31	19.58	17.94	37.52	5.86	21.54	22.69
0.48	3.71	15.61	3.35	18.97	17.83	36.80	5.78	21.37	21.57
0.50	3.85	14.98	3.40	18.38	17.73	36.11	5.69	21.20	20.51

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	3.99	14.38	3.44	17.83	17.62	35.45	5.61	21.03	19.50
0.54	4.13	13.81	3.49	17.30	17.52	34.82	5.52	20.86	18.55
0.56	4.28	13.26	3.53	16.80	17.42	34.21	5.44	20.70	17.65
0.58	4.42	12.74	3.58	16.32	17.32	33.63	5.36	20.54	16.79
0.60	4.56	12.24	3.62	15.86	17.22	33.08	5.29	20.37	15.97
0.62	4.71	11.76	3.66	15.42	17.12	32.54	5.21	20.21	15.20
0.64	4.85	11.31	3.70	15.01	17.02	32.03	5.14	20.06	14.47
0.66	4.99	10.87	3.74	14.61	16.92	31.54	5.07	19.90	13.77
0.68	5.14	10.45	3.78	14.23	16.83	31.06	5.00	19.75	13.11
0.70	5.28	10.05	3.82	13.87	16.73	30.60	5.00	19.59	12.48
0.72	5.43	9.67	3.85	13.52	16.64	30.16	5.00	19.44	11.88
0.74	5.57	9.30	3.89	13.19	16.54	29.74	5.00	19.29	11.31
0.76	5.72	8.95	3.93	12.88	16.45	29.33	5.00	19.14	10.77
0.78	5.86	8.61	3.96	12.58	16.36	28.93	5.00	18.99	10.26
0.80	6.01	8.29	4.00	12.29	16.27	28.55	5.00	18.85	9.77
0.82	6.15	7.98	4.03	12.01	16.18	28.19	5.00	18.70	9.30
0.84	6.30	7.68	4.06	11.74	16.09	27.83	5.00	18.56	8.86
0.86	6.45	7.40	4.09	11.49	16.00	27.49	5.00	18.42	8.44
0.88	6.59	7.12	4.13	11.25	15.91	27.16	5.00	18.28	8.04
0.90	6.74	6.86	4.16	11.01	15.82	26.84	5.00	18.14	7.66
0.92	6.89	6.60	4.19	10.79	15.73	26.53	5.00	18.00	7.29
0.94	7.03	6.36	4.22	10.58	15.65	26.23	5.00	17.86	6.95
0.96	7.18	6.13	4.25	10.37	15.56	25.94	5.00	17.73	6.62
0.98	7.33	5.90	4.27	10.18	15.48	25.66	5.00	17.59	6.30
1.00	7.48	5.69	4.30	9.99	15.39	25.38	5.00	17.46	6.00
1.02	7.63	5.48	4.33	9.81	15.31	25.12	5.00	17.33	5.72

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967, WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	7.77	5.28	4.36	9.64	15.23	24.86	5.00	17.20	5.45
1.06	7.92	5.09	4.38	9.47	15.15	24.62	5.00	17.07	5.19
1.08	8.07	4.91	4.41	9.31	15.06	24.38	5.00	16.94	4.95
1.10	8.22	4.73	4.43	9.16	14.98	24.14	5.00	16.82	4.71
1.12	8.37	4.56	4.46	9.02	14.90	23.92	5.00	16.69	4.49
1.14	8.52	4.39	4.48	8.88	14.82	23.70	5.00	16.56	4.28
1.16	8.67	4.24	4.51	8.74	14.74	23.49	5.00	16.44	4.07
1.18	8.82	4.08	4.53	8.61	14.67	23.28	5.00	16.32	3.88
1.20	8.97	3.94	4.55	8.49	14.59	23.08	5.00	16.20	3.70
1.22	9.12	3.80	4.57	8.37	14.51	22.88	5.00	16.08	3.52
1.24	9.27	3.66	4.60	8.26	14.43	22.69	5.00	15.96	3.36
1.26	9.42	3.53	4.62	8.15	14.36	22.51	5.00	15.84	3.20
1.28	9.57	3.41	4.64	8.05	14.28	22.33	5.00	15.72	3.05
1.30	9.73	3.29	4.66	7.95	14.21	22.15	5.00	15.61	2.91
1.32	9.88	3.17	4.68	7.85	14.13	21.98	5.00	15.49	2.77
1.34	10.03	3.06	4.70	7.76	14.06	21.82	5.00	15.38	2.64
1.36	10.18	2.95	4.72	7.67	13.99	21.66	5.00	15.27	2.51
1.38	10.33	2.85	4.74	7.59	13.91	21.50	5.00	15.15	2.40
1.40	10.49	2.75	4.76	7.51	13.84	21.35	5.00	15.04	2.28
1.42	10.64	2.65	4.78	7.43	13.77	21.20	5.00	14.93	2.18
1.44	10.79	2.56	4.80	7.35	13.70	21.05	5.00	14.82	2.07
1.46	10.95	2.47	4.82	7.28	13.63	20.91	5.00	14.72	1.98
1.48	11.10	2.38	4.83	7.22	13.56	20.77	5.00	14.61	1.88
1.50	11.25	2.30	4.85	7.15	13.49	20.64	5.00	14.50	1.80
1.52	11.41	2.22	4.87	7.09	13.42	20.51	5.00	14.40	1.71
1.54	11.56	2.14	4.89	7.03	13.35	20.38	5.00	14.29	1.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS : BOD DATA FOR JANUARY, 1967, WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

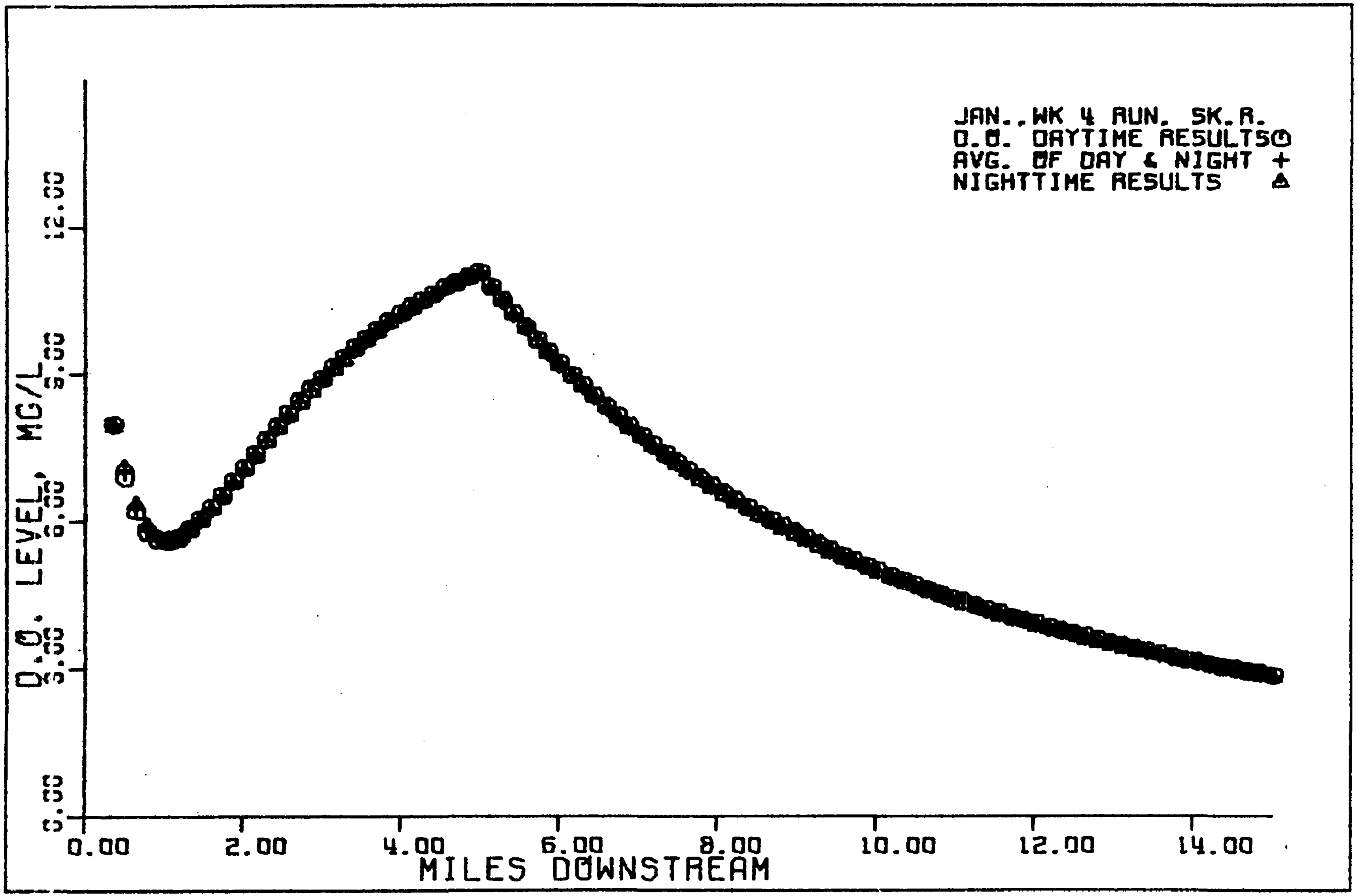
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	11.72	2.07	4.90	6.97	13.28	20.25	5.00	14.19	1.55
1.58	11.87	1.99	4.92	6.92	13.22	20.13	5.00	14.09	1.48
1.60	12.03	1.93	4.94	6.86	13.15	20.01	5.00	13.98	1.41
1.62	12.18	1.86	4.95	6.81	13.08	19.90	5.00	13.88	1.35
1.64	12.34	1.79	4.97	6.76	13.02	19.78	5.00	13.78	1.28
1.66	12.49	1.73	4.99	6.72	12.95	19.67	5.00	13.69	1.22
1.68	12.65	1.67	5.00	6.67	12.89	19.56	5.00	13.59	1.17
1.70	12.80	1.61	5.02	6.63	12.82	19.45	5.00	13.49	1.11
1.72	12.96	1.56	5.03	6.59	12.76	19.35	5.00	13.39	1.06
1.74	13.12	1.51	5.05	6.55	12.70	19.25	5.00	13.30	1.01
1.76	13.27	1.45	5.06	6.52	12.63	19.15	5.00	13.20	0.96
1.78	13.43	1.40	5.08	6.48	12.57	19.05	5.00	13.11	0.92
1.80	13.59	1.36	5.09	6.45	12.51	18.95	5.00	13.01	0.88
1.82	13.74	1.31	5.10	6.41	12.45	18.86	5.00	12.92	0.83
1.84	13.90	1.27	5.12	6.38	12.38	18.77	5.00	12.83	0.80
1.86	14.06	1.22	5.13	6.35	12.32	18.68	5.00	12.74	0.76
1.88	14.22	1.18	5.15	6.33	12.26	18.59	5.00	12.65	0.72
1.90	14.38	1.14	5.16	6.30	12.20	18.50	5.00	12.56	0.69
1.92	14.53	1.10	5.17	6.27	12.14	18.42	5.00	12.47	0.66
1.94	14.69	1.06	5.19	6.25	12.08	18.34	5.00	12.38	0.63
1.96	14.85	1.03	5.20	6.23	12.03	18.25	5.00	12.30	0.60
1.98	15.01	0.99	5.21	6.21	11.97	18.17	5.00	12.21	0.57

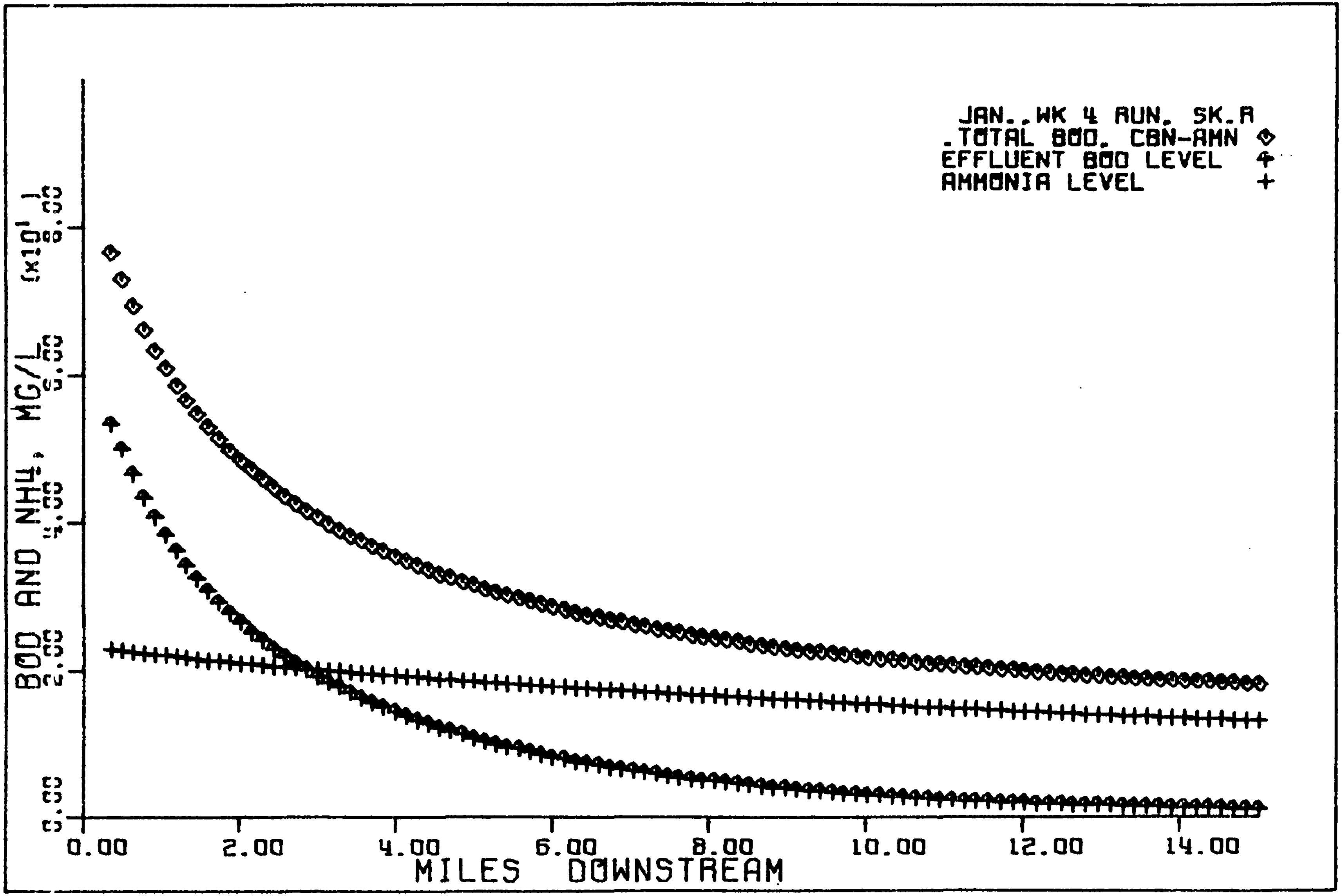
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, AMES GAGING STATION TO COLFAX REACH
CONDITIONS :
BOD DATA FOR JANUARY, 1967,WK 4, ICE COVER AT MILE 5
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	7.98	0.37	0.0	7.94	0.37	0.0
MINIMUM DO, MG/L	2.85	15.01	1.98	2.80	15.01	1.98
FINAL DO, MG/L	9.21	6.01	0.80	9.17	6.01	0.80
DO DEFICIT						
INITIAL, MG/L	2.53	0.37	0.0	2.57	0.37	0.0
FINAL, MG/L	4.96	6.01	0.80	5.00	6.01	0.80
RIVER DISCHARGE						
INITIAL, CFS	5.61	0.37	0.0	5.61	0.37	0.0
FINAL, CFS	6.74	6.01	0.80	6.74	6.01	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	52.95	0.37	0.0	52.95	0.37	0.0
FINAL, DEG F	32.21	6.01	0.80	32.21	6.01	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	53.33	0.37	0.0	53.33	0.37	0.0
FINAL BOD, MG/L	8.24	6.01	0.80	8.34	6.01	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.18	0.37	0.0	0.18	0.37	0.0
FINAL BOD IN RIVER	3.95	6.01	0.80	4.04	6.01	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	21.01	0.37	0.0	21.01	0.37	0.0
FINAL BOD, MG/L	16.27	6.01	0.80	16.27	6.01	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	76.29	0.37	0.0	76.83	0.37	0.0
FINAL VALUE, MG/L	28.46	6.01	0.80	28.64	6.01	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	23.04	0.37	0.0	23.04	0.37	0.0
FINAL VALUE, MG/L	17.84	6.01	0.80	17.84	6.01	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	9.10	0.37	0.0	9.10	0.37	0.0
FINAL VALUE, MG/L	5.00	6.01	0.80	5.00	6.01	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	26.46	0.37	0.0	26.46	0.37	0.0
FINAL VALUE, MG/L	18.85	6.01	0.80	18.85	6.01	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	91.09	0.37	0.0	91.09	0.37	0.0
FINAL PERCENT	9.77	6.01	0.80	9.77	6.01	0.80


JAN.,WK 4 RUN, SK.R.
D.O. DAYTIME RESULTS ⊙
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


JAN..WK 4 RUN. SK.R
.TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10^1)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

L. Simulation Results for Winter Period, 1969, with Low Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.72	50.00	75.00	0.0	55.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	75.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
40.00	0.60	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2P
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 1.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 5.76 CFS, RIVER Q = 40.00 CFS, TOTAL Q = 45.76 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 0.80 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		40.0	10.66	9.95		0.40
0.0	0.37	34.3	34.3	34.3	45.8	10.35	9.73	10.04	3.50
0.02	0.67	34.0	34.0	34.0	45.9	10.38	9.87	10.12	3.43
0.04	0.97	33.8	33.8	33.8	46.1	10.41	9.97	10.19	3.36
0.06	1.27	33.6	33.6	33.6	46.3	10.45	10.07	10.26	3.30
0.08	1.57	33.4	33.4	33.4	46.5	10.50	10.17	10.33	3.23
0.10	1.87	33.3	33.3	33.3	46.7	10.55	10.26	10.41	3.17
0.12	2.17	33.1	33.1	33.1	46.8	10.61	10.36	10.48	3.11
0.14	2.47	33.0	33.0	33.0	47.0	10.67	10.45	10.56	3.05
0.16	2.77	32.9	32.9	32.9	47.2	10.73	10.53	10.63	2.99
0.18	3.07	32.8	32.8	32.8	47.4	10.79	10.62	10.70	2.94
0.20	3.37	32.7	32.7	32.7	47.6	10.85	10.70	10.77	2.88
0.22	3.68	32.6	32.6	32.6	47.7	10.91	10.78	10.84	2.83
0.24	3.98	32.6	32.6	32.6	47.9	10.97	10.86	10.91	2.78
0.26	4.28	32.5	32.5	32.5	48.1	11.03	10.93	10.98	2.73
0.28	4.59	32.5	32.5	32.5	48.3	11.09	11.00	11.04	2.68
0.30	4.89	32.4	32.4	32.4	48.5	10.77	10.68	10.73	2.63
0.32	5.20	32.4	32.4	32.4	48.7	10.46	10.38	10.42	2.58
0.34	5.50	32.3	32.3	32.3	48.8	10.17	10.08	10.12	2.53
0.36	5.81	32.3	32.3	32.3	49.0	9.88	9.79	9.84	2.49
0.38	6.12	32.3	32.3	32.3	49.2	9.60	9.51	9.56	2.44
0.40	6.42	32.2	32.2	32.2	49.4	9.33	9.24	9.29	2.40
0.42	6.73	32.2	32.2	32.2	49.6	9.07	8.98	9.03	2.36
0.44	7.04	32.2	32.2	32.2	49.8	8.82	8.73	8.78	2.31
0.46	7.35	32.2	32.2	32.2	49.9	8.58	8.49	8.54	2.27
0.48	7.65	32.1	32.1	32.1	50.1	8.35	8.26	8.30	2.23
0.50	7.96	32.1	32.1	32.1	50.3	8.12	8.03	8.08	2.19

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.27	32.1	32.1	32.1	50.5	7.90	7.81	7.86	2.15
0.54	8.58	32.1	32.1	32.1	50.7	7.69	7.60	7.65	2.11
0.56	8.89	32.1	32.1	32.1	50.9	7.49	7.40	7.45	2.08
0.58	9.20	32.1	32.1	32.1	51.1	7.30	7.21	7.25	2.04
0.60	9.51	32.1	32.1	32.1	51.2	7.11	7.02	7.06	2.00
0.62	9.82	32.1	32.1	32.1	51.4	6.93	6.84	6.88	1.97
0.64	10.14	32.1	32.1	32.1	51.6	6.75	6.66	6.71	1.93
0.66	10.45	32.1	32.1	32.1	51.8	6.58	6.49	6.54	1.90
0.68	10.76	32.0	32.0	32.0	52.0	6.42	6.33	6.38	1.87
0.70	11.07	32.0	32.0	32.0	52.2	6.27	6.18	6.22	1.83
0.72	11.39	32.0	32.0	32.0	52.4	6.11	6.03	6.07	1.80
0.74	11.70	32.0	32.0	32.0	52.6	5.97	5.88	5.93	1.77
0.76	12.02	32.0	32.0	32.0	52.7	5.83	5.74	5.79	1.74
0.78	12.33	32.0	32.0	32.0	52.9	5.70	5.61	5.65	1.71
0.80	12.65	32.0	32.0	32.0	53.1	5.57	5.48	5.52	1.68
0.82	12.96	32.0	32.0	32.0	53.3	5.44	5.36	5.40	1.65
0.84	13.28	32.0	32.0	32.0	53.5	5.32	5.24	5.28	1.62
0.86	13.59	32.0	32.0	32.0	53.7	5.21	5.12	5.17	1.59
0.88	13.91	32.0	32.0	32.0	53.9	5.10	5.01	5.06	1.56
0.90	14.23	32.0	32.0	32.0	54.1	4.99	4.91	4.95	1.54
0.92	14.55	32.0	32.0	32.0	54.3	4.89	4.81	4.85	1.51
0.94	14.86	32.0	32.0	32.0	54.5	4.79	4.71	4.75	1.48
0.96	15.18	32.0	32.0	32.0	54.6	4.70	4.62	4.66	1.46
0.98	15.50	32.0	32.0	32.0	54.8	4.61	4.53	4.57	1.43
1.00	15.82	32.0	32.0	32.0	55.0	4.52	4.44	4.48	1.41
1.02	16.14	32.0	32.0	32.0	55.2	4.44	4.36	4.40	1.38

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	16.46	32.0	32.0	32.0	55.4	4.36	4.28	4.32	1.36
1.06	16.78	32.0	32.0	32.0	55.6	4.28	4.20	4.24	1.34
1.08	17.10	32.0	32.0	32.0	55.8	4.21	4.13	4.17	1.31
1.10	17.42	32.0	32.0	32.0	56.0	4.14	4.06	4.10	1.29
1.12	17.75	32.0	32.0	32.0	56.2	4.07	3.99	4.03	1.27
1.14	18.07	32.0	32.0	32.0	56.4	4.00	3.93	3.97	1.25
1.16	18.39	32.0	32.0	32.0	56.6	3.94	3.86	3.90	1.23
1.18	18.71	32.0	32.0	32.0	56.8	3.88	3.80	3.84	1.21
1.20	19.04	32.0	32.0	32.0	57.0	3.82	3.75	3.79	1.18
1.22	19.36	32.0	32.0	32.0	57.2	3.77	3.69	3.73	1.16
1.24	19.69	32.0	32.0	32.0	57.3	3.72	3.64	3.68	1.14
1.26	20.01	32.0	32.0	32.0	57.5	3.67	3.59	3.63	1.13
1.28	20.34	32.0	32.0	32.0	57.7	3.62	3.54	3.58	1.11
1.30	20.66	32.0	32.0	32.0	57.9	3.57	3.50	3.53	1.09
1.32	20.99	32.0	32.0	32.0	58.1	3.52	3.45	3.49	1.07
1.34	21.31	32.0	32.0	32.0	58.3	3.48	3.41	3.45	1.05
1.36	21.64	32.0	32.0	32.0	58.5	3.44	3.37	3.40	1.03
1.38	21.97	32.0	32.0	32.0	58.7	3.40	3.33	3.36	1.02
1.40	22.30	32.0	32.0	32.0	58.9	3.36	3.29	3.33	1.00
1.42	22.62	32.0	32.0	32.0	59.1	3.33	3.26	3.29	0.98
1.44	22.95	32.0	32.0	32.0	59.3	3.29	3.22	3.26	0.97
1.46	23.28	32.0	32.0	32.0	59.5	3.26	3.19	3.22	0.95
1.48	23.61	32.0	32.0	32.0	59.7	3.22	3.16	3.19	0.93
1.50	23.94	32.0	32.0	32.0	59.9	3.19	3.12	3.16	0.92
1.52	24.27	32.0	32.0	32.0	60.1	3.16	3.10	3.13	0.90
1.54	24.60	32.0	32.0	32.0	60.3	3.13	3.07	3.10	0.89

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	24.93	32.0	32.0	32.0	60.5	3.10	3.04	3.07	0.87
1.58	25.26	32.0	32.0	32.0	60.7	3.08	3.01	3.05	0.86
1.60	25.59	32.0	32.0	32.0	60.9	3.05	2.99	3.02	0.84
1.62	25.93	32.0	32.0	32.0	61.1	3.03	2.96	2.99	0.83
1.64	26.26	32.0	32.0	32.0	61.3	3.00	2.94	2.97	0.82
1.66	26.59	32.0	32.0	32.0	61.5	2.98	2.91	2.95	0.80
1.68	26.93	32.0	32.0	32.0	61.7	2.95	2.89	2.92	0.79
1.70	27.26	32.0	32.0	32.0	61.9	2.93	2.87	2.90	0.78
1.72	27.59	32.0	32.0	32.0	62.1	2.91	2.85	2.88	0.76
1.74	27.93	32.0	32.0	32.0	62.3	2.89	2.83	2.86	0.75
1.76	28.26	32.0	32.0	32.0	62.5	2.87	2.81	2.84	0.74
1.78	28.60	32.0	32.0	32.0	62.7	2.85	2.79	2.82	0.73
1.80	28.93	32.0	32.0	32.0	62.9	2.83	2.77	2.80	0.72
1.82	29.27	32.0	32.0	32.0	63.1	2.81	2.75	2.78	0.70
1.84	29.61	32.0	32.0	32.0	63.3	2.79	2.73	2.76	0.69
1.86	29.94	32.0	32.0	32.0	63.5	2.77	2.71	2.74	0.68
1.88	30.28	32.0	32.0	32.0	63.7	2.75	2.69	2.72	0.67
1.90	30.62	32.0	32.0	32.0	63.9	2.73	2.67	2.70	0.66
1.92	30.96	32.0	32.0	32.0	64.1	2.71	2.65	2.68	0.65
1.94	31.30	32.0	32.0	32.0	64.3	2.69	2.63	2.66	0.64
1.96	31.63	32.0	32.0	32.0	64.5	2.67	2.62	2.64	0.63
1.98	31.97	32.0	32.0	32.0	64.7	2.65	2.60	2.62	0.62

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.77	2.77	0.55	3.32	3.00	0.40	0.10
0.0	0.37	10.95	0.89	11.84	4.78	16.62	3.25	4.13	12.67
0.02	0.67	10.65	0.91	11.56	4.69	16.25	3.23	4.09	12.04
0.04	0.97	10.31	0.93	11.24	4.60	15.84	3.20	4.05	11.45
0.06	1.27	9.98	0.95	10.93	4.51	15.44	3.18	4.02	10.88
0.08	1.57	9.67	0.97	10.64	4.42	15.06	3.15	3.98	10.35
0.10	1.87	9.37	0.99	10.36	4.34	14.70	3.13	3.95	9.85
0.12	2.17	9.08	1.01	10.09	4.25	14.34	3.10	3.91	9.37
0.14	2.47	8.81	1.03	9.83	4.17	14.01	3.08	3.88	8.92
0.16	2.77	8.54	1.04	9.58	4.10	13.68	3.05	3.85	8.49
0.18	3.07	8.28	1.06	9.35	4.02	13.37	3.03	3.81	8.08
0.20	3.37	8.04	1.08	9.12	3.95	13.06	3.01	3.78	7.69
0.22	3.68	7.80	1.10	8.90	3.87	12.77	3.00	3.75	7.32
0.24	3.98	7.57	1.12	8.69	3.80	12.49	3.00	3.72	6.98
0.26	4.28	7.35	1.14	8.49	3.73	12.22	3.00	3.69	6.64
0.28	4.59	7.13	1.15	8.29	3.66	11.95	3.00	3.65	6.33
0.30	4.89	6.93	1.17	8.10	3.60	11.70	3.00	3.62	6.03
0.32	5.20	6.73	1.19	7.92	3.53	11.45	3.00	3.59	5.74
0.34	5.50	6.54	1.21	7.75	3.47	11.21	3.00	3.56	5.47
0.36	5.81	6.35	1.23	7.58	3.40	10.98	3.00	3.53	5.21
0.38	6.12	6.17	1.24	7.42	3.34	10.76	3.00	3.50	4.97
0.40	6.42	6.00	1.26	7.26	3.28	10.54	3.00	3.48	4.73
0.42	6.73	5.83	1.28	7.11	3.22	10.33	3.00	3.45	4.51
0.44	7.04	5.67	1.30	6.96	3.17	10.13	3.00	3.42	4.30
0.46	7.35	5.51	1.31	6.82	3.11	9.93	3.00	3.39	4.10
0.48	7.65	5.36	1.33	6.69	3.05	9.74	3.00	3.36	3.90
0.50	7.96	5.21	1.35	6.56	3.00	9.56	3.00	3.34	3.72

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.27	5.07	1.37	6.43	2.95	9.38	3.00	3.31	3.55
0.54	8.58	4.93	1.38	6.31	2.89	9.20	3.00	3.28	3.38
0.56	8.89	4.80	1.40	6.19	2.84	9.04	3.00	3.25	3.22
0.58	9.20	4.67	1.42	6.08	2.79	8.87	3.00	3.23	3.07
0.60	9.51	4.54	1.43	5.97	2.74	8.71	3.00	3.20	2.93
0.62	9.82	4.42	1.45	5.87	2.69	8.56	3.00	3.18	2.79
0.64	10.14	4.30	1.47	5.77	2.65	8.41	3.00	3.15	2.66
0.66	10.45	4.19	1.48	5.67	2.60	8.27	3.00	3.12	2.53
0.68	10.76	4.07	1.50	5.57	2.55	8.13	3.00	3.10	2.42
0.70	11.07	3.97	1.52	5.48	2.51	7.99	3.00	3.07	2.30
0.72	11.39	3.86	1.53	5.39	2.46	7.86	3.00	3.05	2.20
0.74	11.70	3.76	1.55	5.31	2.42	7.73	3.00	3.02	2.09
0.76	12.02	3.66	1.56	5.23	2.38	7.60	3.00	3.00	2.00
0.78	12.33	3.57	1.58	5.15	2.34	7.48	3.00	2.98	1.90
0.80	12.65	3.47	1.60	5.07	2.30	7.37	3.00	2.95	1.81
0.82	12.96	3.38	1.61	5.00	2.26	7.25	3.00	2.93	1.73
0.84	13.28	3.30	1.63	4.93	2.22	7.14	3.00	2.91	1.65
0.86	13.59	3.21	1.64	4.86	2.18	7.03	3.00	2.88	1.57
0.88	13.91	3.13	1.66	4.79	2.14	6.93	3.00	2.86	1.50
0.90	14.23	3.05	1.68	4.73	2.10	6.83	3.00	2.84	1.43
0.92	14.55	2.97	1.69	4.66	2.07	6.73	3.00	2.81	1.36
0.94	14.86	2.90	1.71	4.60	2.03	6.63	3.00	2.79	1.30
0.96	15.18	2.82	1.72	4.55	1.99	6.54	3.00	2.77	1.24
0.98	15.50	2.75	1.74	4.49	1.96	6.45	3.00	2.75	1.18
1.00	15.82	2.68	1.75	4.44	1.93	6.36	3.00	2.73	1.13
1.02	16.14	2.62	1.77	4.39	1.89	6.28	3.00	2.70	1.07

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	16.46	2.55	1.78	4.34	1.86	6.20	3.00	2.68	1.03
1.06	16.78	2.49	1.80	4.29	1.83	6.12	3.00	2.66	0.98
1.08	17.10	2.43	1.82	4.24	1.80	6.04	3.00	2.64	0.93
1.10	17.42	2.37	1.83	4.20	1.77	5.96	3.00	2.62	0.89
1.12	17.75	2.31	1.85	4.15	1.74	5.89	3.00	2.60	0.85
1.14	18.07	2.25	1.86	4.11	1.71	5.82	3.00	2.58	0.81
1.16	18.39	2.19	1.88	4.07	1.68	5.75	3.00	2.56	0.77
1.18	18.71	2.14	1.89	4.03	1.65	5.68	3.00	2.54	0.74
1.20	19.04	2.09	1.91	3.99	1.62	5.61	3.00	2.52	0.70
1.22	19.36	2.04	1.92	3.96	1.59	5.55	3.00	2.50	0.67
1.24	19.69	1.99	1.94	3.92	1.57	5.49	3.00	2.48	0.64
1.26	20.01	1.94	1.95	3.89	1.54	5.43	3.00	2.46	0.61
1.28	20.34	1.89	1.97	3.86	1.51	5.37	3.00	2.44	0.58
1.30	20.66	1.85	1.98	3.83	1.49	5.32	3.00	2.42	0.55
1.32	20.99	1.80	2.00	3.80	1.46	5.26	3.00	2.40	0.53
1.34	21.31	1.76	2.01	3.77	1.44	5.21	3.00	2.39	0.50
1.36	21.64	1.72	2.03	3.74	1.41	5.16	3.00	2.37	0.48
1.38	21.97	1.68	2.04	3.72	1.39	5.11	3.00	2.35	0.46
1.40	22.30	1.64	2.05	3.69	1.37	5.06	3.00	2.33	0.44
1.42	22.62	1.60	2.07	3.67	1.34	5.01	3.00	2.31	0.42
1.44	22.95	1.56	2.08	3.64	1.32	4.96	3.00	2.30	0.40
1.46	23.28	1.52	2.10	3.62	1.30	4.92	3.00	2.28	0.38
1.48	23.61	1.49	2.11	3.60	1.28	4.88	3.00	2.26	0.36
1.50	23.94	1.45	2.13	3.58	1.26	4.83	3.00	2.24	0.35
1.52	24.27	1.42	2.14	3.56	1.24	4.79	3.00	2.23	0.33
1.54	24.60	1.38	2.16	3.54	1.21	4.75	3.00	2.21	0.32

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

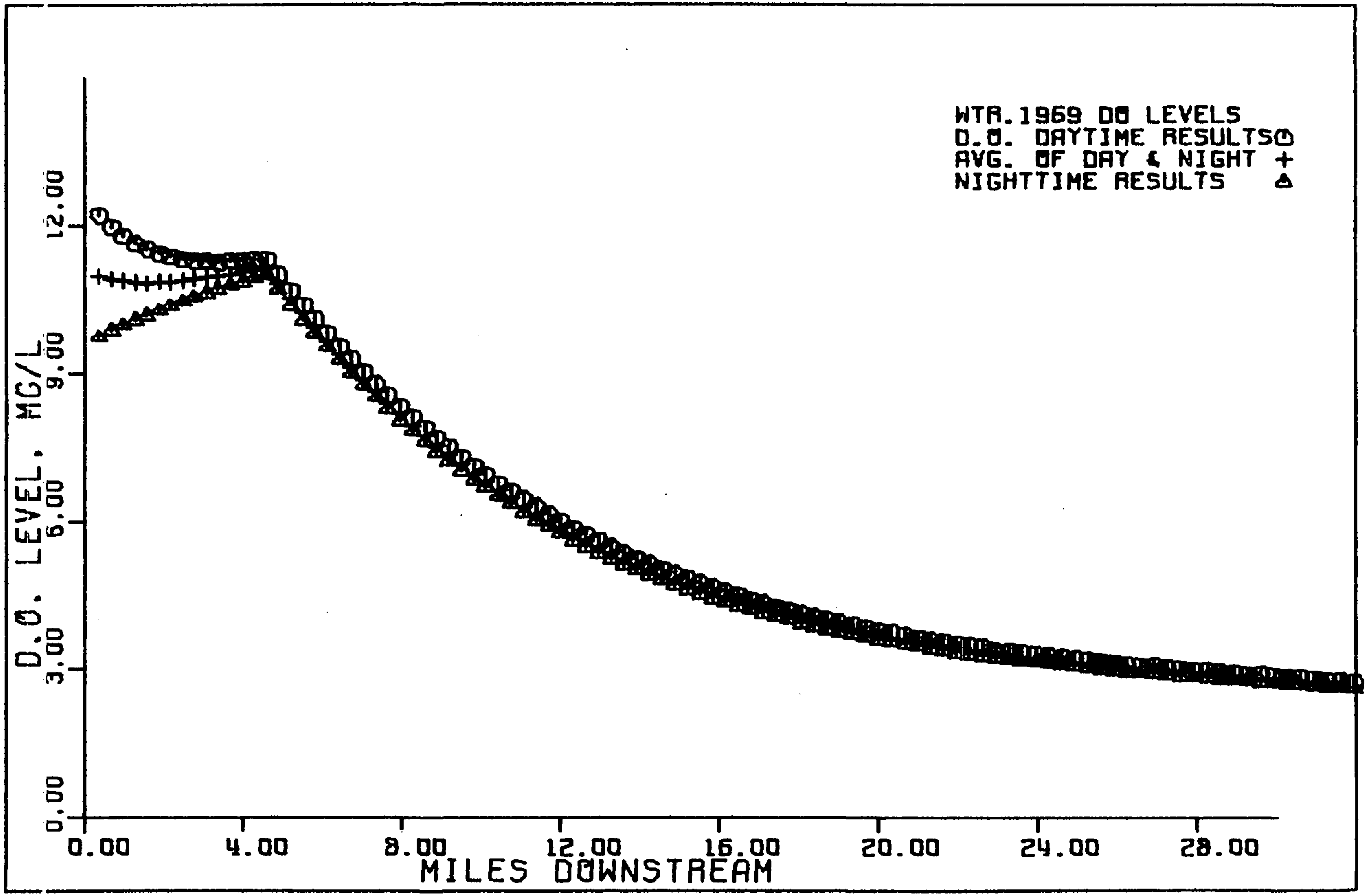
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	24.93	1.35	2.17	3.52	1.19	4.71	3.00	2.19	0.30
1.58	25.26	1.32	2.18	3.50	1.18	4.68	3.00	2.18	0.29
1.60	25.59	1.29	2.20	3.49	1.16	4.64	3.00	2.16	0.28
1.62	25.93	1.26	2.21	3.47	1.14	4.61	3.00	2.14	0.26
1.64	26.26	1.23	2.23	3.45	1.12	4.57	3.00	2.13	0.25
1.66	26.59	1.20	2.24	3.44	1.10	4.54	3.00	2.11	0.24
1.68	26.93	1.17	2.26	3.43	1.08	4.51	3.00	2.10	0.23
1.70	27.26	1.14	2.27	3.41	1.06	4.48	3.00	2.08	0.22
1.72	27.59	1.12	2.28	3.40	1.05	4.45	3.00	2.06	0.21
1.74	27.93	1.09	2.30	3.39	1.03	4.42	3.00	2.05	0.20
1.76	28.26	1.07	2.31	3.38	1.01	4.39	3.00	2.03	0.19
1.78	28.60	1.04	2.32	3.37	1.00	4.36	3.00	2.02	0.18
1.80	28.93	1.02	2.34	3.36	0.98	4.34	3.00	2.00	0.17
1.82	29.27	0.99	2.35	3.35	0.96	4.31	3.00	1.99	0.17
1.84	29.61	0.97	2.37	3.34	0.95	4.29	3.00	1.97	0.16
1.86	29.94	0.95	2.38	3.33	0.93	4.26	3.00	1.96	0.15
1.88	30.28	0.93	2.39	3.32	0.92	4.24	3.00	1.94	0.14
1.90	30.62	0.91	2.41	3.31	0.90	4.22	3.00	1.93	0.14
1.92	30.96	0.89	2.42	3.31	0.89	4.19	3.00	1.91	0.13
1.94	31.30	0.86	2.43	3.30	0.88	4.17	3.00	1.90	0.13
1.96	31.63	0.85	2.45	3.29	0.86	4.15	3.00	1.89	0.12
1.98	31.97	0.83	2.46	3.29	0.85	4.13	3.00	1.87	0.12

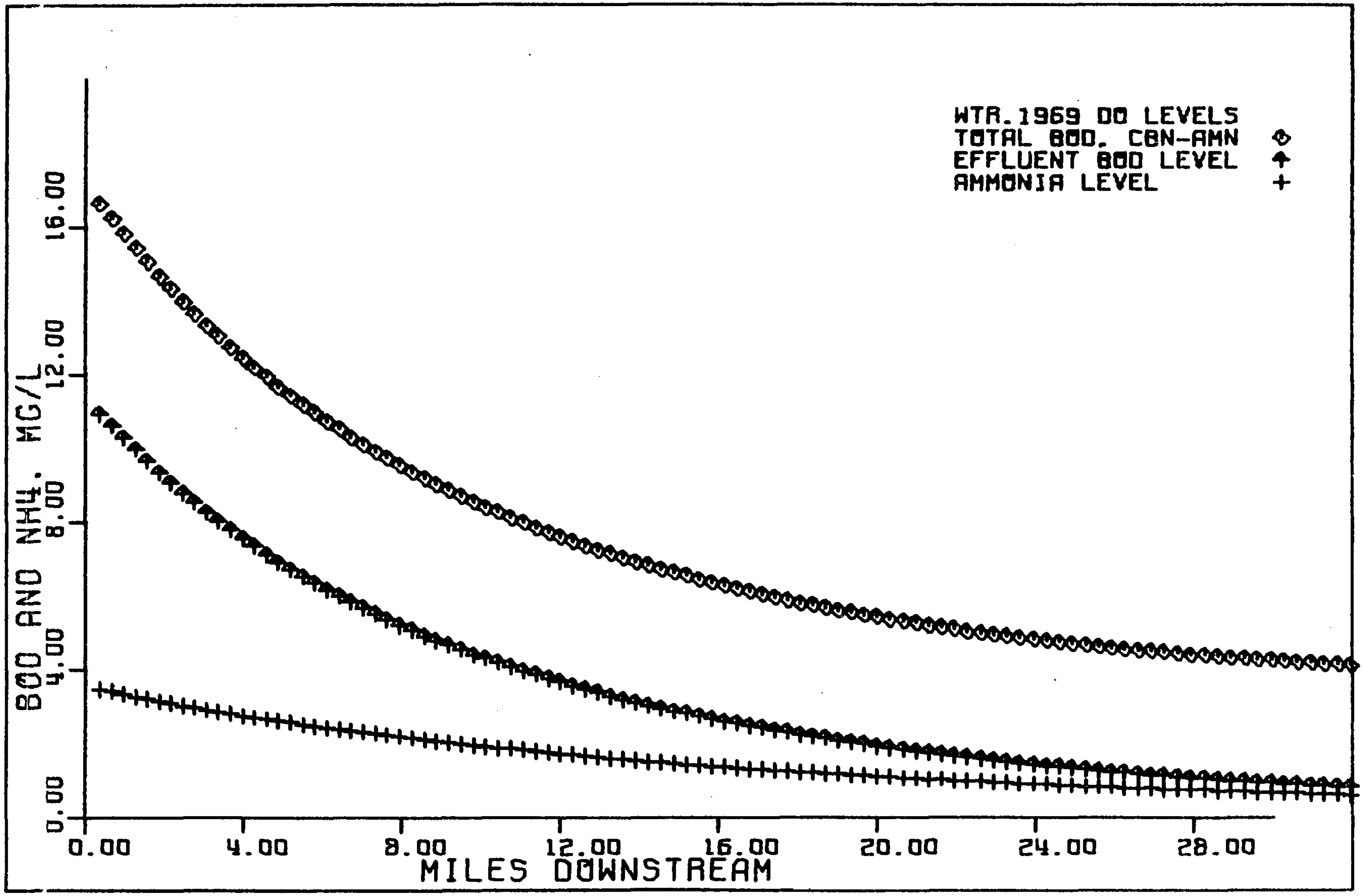
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	10.35	0.37	0.0	9.73	0.37	0.0
MINIMUM DO, MG/L	2.65	31.97	1.98	2.60	31.97	1.98
FINAL DO, MG/L	5.57	12.65	0.80	5.48	12.65	0.80
DO DEFICIT						
INITIAL, MG/L	3.37	0.37	0.0	4.00	0.37	0.0
FINAL, MG/L	8.64	12.65	0.80	8.73	12.65	0.80
RIVER DISCHARGE						
INITIAL, CFS	45.76	0.37	0.0	45.76	0.37	0.0
FINAL, CFS	53.12	12.65	0.80	53.12	12.65	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	34.27	0.37	0.0	34.27	0.37	0.0
FINAL, DEG F	32.02	12.65	0.80	32.02	12.65	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	10.95	0.37	0.0	10.95	0.37	0.0
FINAL BOD, MG/L	3.47	12.65	0.80	3.48	12.65	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.05	0.37	0.0	0.05	0.37	0.0
FINAL BOD IN RIVER	1.56	12.65	0.80	1.63	12.65	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	4.78	0.37	0.0	4.78	0.37	0.0
FINAL BOD, MG/L	2.30	12.65	0.80	2.30	12.65	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	16.51	0.37	0.0	16.74	0.37	0.0
FINAL VALUE, MG/L	7.32	12.65	0.80	7.41	12.65	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	3.50	0.37	0.0	3.50	0.37	0.0
FINAL VALUE, MG/L	1.68	12.65	0.80	1.68	12.65	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.25	0.37	0.0	3.25	0.37	0.0
FINAL VALUE, MG/L	3.00	12.65	0.80	3.00	12.65	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.13	0.37	0.0	4.13	0.37	0.0
FINAL VALUE, MG/L	2.95	12.65	0.80	2.95	12.65	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	12.67	0.37	0.0	12.67	0.37	0.0
FINAL PERCENT	1.81	12.65	0.80	1.81	12.65	0.80


WTR. 1969 DO LEVELS
D.O. DAYTIME RESULTS O
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM


WTR.1969 DO LEVELS
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4. MG/L
0.00
4.00
8.00
12.00
16.00
MILES DOWNSTREAM
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00

M. Simulation Results for Winter Period, 1959, with

High Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.72	50.00	75.00	0.0	55.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	95.00	75.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNP	KDR
40.00	0.60	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICF	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.300	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLOCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 1.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 5.76 CFS, RIVER Q = 40.00 CFS, TOTAL Q = 45.76 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 0.80 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		40.0	13.50	10.66		0.40
0.0	0.37	34.3	34.3	34.3	45.8	12.83	10.35	11.59	3.50
0.02	0.67	34.0	34.0	34.0	45.9	12.51	10.40	11.46	3.43
0.04	0.97	33.8	33.8	33.8	46.1	12.25	10.43	11.34	3.36
0.06	1.27	33.6	33.6	33.6	46.3	12.03	10.46	11.25	3.30
0.08	1.57	33.4	33.4	33.4	46.5	11.86	10.51	11.18	3.23
0.10	1.87	33.3	33.3	33.3	46.7	11.72	10.56	11.14	3.17
0.12	2.17	33.1	33.1	33.1	46.8	11.62	10.61	11.11	3.11
0.14	2.47	33.0	33.0	33.0	47.0	11.54	10.66	11.10	3.05
0.16	2.77	32.9	32.9	32.9	47.2	11.47	10.72	11.10	2.99
0.18	3.07	32.8	32.8	32.8	47.4	11.43	10.78	11.11	2.94
0.20	3.37	32.7	32.7	32.7	47.6	11.40	10.84	11.12	2.88
0.22	3.68	32.6	32.6	32.6	47.7	11.39	10.90	11.14	2.83
0.24	3.98	32.6	32.6	32.6	47.9	11.38	10.96	11.17	2.78
0.26	4.28	32.5	32.5	32.5	48.1	11.39	11.02	11.20	2.73
0.28	4.59	32.5	32.5	32.5	48.3	11.40	11.08	11.24	2.68
0.30	4.89	32.4	32.4	32.4	48.5	11.09	10.77	10.93	2.63
0.32	5.20	32.4	32.4	32.4	48.7	10.79	10.48	10.63	2.58
0.34	5.50	32.3	32.3	32.3	48.8	10.50	10.20	10.35	2.53
0.36	5.81	32.3	32.3	32.3	49.0	10.23	9.93	10.08	2.49
0.38	6.12	32.3	32.3	32.3	49.2	9.97	9.67	9.82	2.44
0.40	6.42	32.2	32.2	32.2	49.4	9.71	9.42	9.56	2.40
0.42	6.73	32.2	32.2	32.2	49.6	9.47	9.18	9.32	2.36
0.44	7.04	32.2	32.2	32.2	49.8	9.23	8.95	9.09	2.31
0.46	7.35	32.2	32.2	32.2	49.9	9.01	8.72	8.87	2.27
0.48	7.65	32.1	32.1	32.1	50.1	8.79	8.51	8.65	2.23
0.50	7.96	32.1	32.1	32.1	50.3	8.59	8.31	8.45	2.19

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.27	32.1	32.1	32.1	50.5	8.39	8.12	8.25	2.15
0.54	8.58	32.1	32.1	32.1	50.7	8.20	7.93	8.06	2.11
0.56	8.89	32.1	32.1	32.1	50.9	8.02	7.75	7.88	2.08
0.58	9.20	32.1	32.1	32.1	51.1	7.84	7.58	7.71	2.04
0.60	9.51	32.1	32.1	32.1	51.2	7.68	7.42	7.55	2.00
0.62	9.82	32.1	32.1	32.1	51.4	7.52	7.26	7.39	1.97
0.64	10.14	32.1	32.1	32.1	51.6	7.37	7.12	7.24	1.93
0.66	10.45	32.1	32.1	32.1	51.8	7.22	6.97	7.10	1.90
0.68	10.76	32.0	32.0	32.0	52.0	7.08	6.84	6.96	1.87
0.70	11.07	32.0	32.0	32.0	52.2	6.95	6.71	6.83	1.83
0.72	11.39	32.0	32.0	32.0	52.4	6.83	6.59	6.71	1.80
0.74	11.70	32.0	32.0	32.0	52.6	6.71	6.47	6.59	1.77
0.76	12.02	32.0	32.0	32.0	52.7	6.59	6.36	6.48	1.74
0.78	12.33	32.0	32.0	32.0	52.9	6.48	6.25	6.37	1.71
0.80	12.65	32.0	32.0	32.0	53.1	6.38	6.15	6.27	1.68
0.82	12.96	32.0	32.0	32.0	53.3	6.28	6.06	6.17	1.65
0.84	13.28	32.0	32.0	32.0	53.5	6.19	5.97	6.08	1.62
0.86	13.59	32.0	32.0	32.0	53.7	6.10	5.88	5.99	1.59
0.88	13.91	32.0	32.0	32.0	53.9	6.01	5.80	5.91	1.56
0.90	14.23	32.0	32.0	32.0	54.1	5.93	5.72	5.83	1.54
0.92	14.55	32.0	32.0	32.0	54.3	5.86	5.65	5.75	1.51
0.94	14.36	32.0	32.0	32.0	54.5	5.79	5.58	5.68	1.48
0.96	15.18	32.0	32.0	32.0	54.6	5.72	5.52	5.62	1.46
0.98	15.50	32.0	32.0	32.0	54.8	5.65	5.46	5.55	1.43
1.00	15.82	32.0	32.0	32.0	55.0	5.59	5.40	5.50	1.41
1.02	16.14	32.0	32.0	32.0	55.2	5.54	5.34	5.44	1.38

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	16.46	32.0	32.0	32.0	55.4	5.48	5.29	5.39	1.36
1.06	16.78	32.0	32.0	32.0	55.6	5.43	5.24	5.34	1.34
1.08	17.10	32.0	32.0	32.0	55.8	5.38	5.20	5.29	1.31
1.10	17.42	32.0	32.0	32.0	56.0	5.34	5.16	5.25	1.29
1.12	17.75	32.0	32.0	32.0	56.2	5.29	5.12	5.21	1.27
1.14	18.07	32.0	32.0	32.0	56.4	5.26	5.08	5.17	1.25
1.16	18.39	32.0	32.0	32.0	56.6	5.22	5.04	5.13	1.23
1.18	18.71	32.0	32.0	32.0	56.8	5.18	5.01	5.10	1.21
1.20	19.04	32.0	32.0	32.0	57.0	5.15	4.98	5.07	1.18
1.22	19.36	32.0	32.0	32.0	57.2	5.12	4.95	5.04	1.16
1.24	19.69	32.0	32.0	32.0	57.3	5.09	4.93	5.01	1.14
1.26	20.01	32.0	32.0	32.0	57.5	5.07	4.90	4.99	1.13
1.28	20.34	32.0	32.0	32.0	57.7	5.04	4.88	4.96	1.11
1.30	20.66	32.0	32.0	32.0	57.9	5.02	4.86	4.94	1.09
1.32	20.99	32.0	32.0	32.0	58.1	5.00	4.84	4.92	1.07
1.34	21.31	32.0	32.0	32.0	58.3	4.98	4.83	4.90	1.05
1.36	21.64	32.0	32.0	32.0	58.5	4.96	4.81	4.89	1.03
1.38	21.97	32.0	32.0	32.0	58.7	4.94	4.80	4.87	1.02
1.40	22.30	32.0	32.0	32.0	58.9	4.93	4.78	4.86	1.00
1.42	22.62	32.0	32.0	32.0	59.1	4.92	4.77	4.84	0.98
1.44	22.95	32.0	32.0	32.0	59.3	4.90	4.76	4.83	0.97
1.46	23.28	32.0	32.0	32.0	59.5	4.89	4.75	4.82	0.95
1.48	23.61	32.0	32.0	32.0	59.7	4.88	4.75	4.81	0.93
1.50	23.94	32.0	32.0	32.0	59.9	4.87	4.74	4.80	0.92
1.52	24.27	32.0	32.0	32.0	60.1	4.86	4.73	4.80	0.90
1.54	24.60	32.0	32.0	32.0	60.3	4.86	4.73	4.79	0.89

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	24.93	32.0	32.0	32.0	60.5	4.85	4.72	4.79	0.87
1.58	25.26	32.0	32.0	32.0	60.7	4.84	4.72	4.78	0.86
1.60	25.59	32.0	32.0	32.0	60.9	4.84	4.71	4.78	0.84
1.62	25.93	32.0	32.0	32.0	61.1	4.83	4.71	4.77	0.83
1.64	26.26	32.0	32.0	32.0	61.3	4.83	4.71	4.77	0.82
1.66	26.59	32.0	32.0	32.0	61.5	4.83	4.71	4.77	0.80
1.68	26.93	32.0	32.0	32.0	61.7	4.82	4.71	4.76	0.79
1.70	27.26	32.0	32.0	32.0	61.9	4.82	4.71	4.76	0.78
1.72	27.59	32.0	32.0	32.0	62.1	4.82	4.71	4.76	0.76
1.74	27.93	32.0	32.0	32.0	62.3	4.82	4.70	4.76	0.75
1.76	28.26	32.0	32.0	32.0	62.5	4.81	4.70	4.76	0.74
1.78	28.60	32.0	32.0	32.0	62.7	4.81	4.70	4.76	0.73
1.80	28.93	32.0	32.0	32.0	62.9	4.81	4.70	4.76	0.72
1.82	29.27	32.0	32.0	32.0	63.1	4.81	4.70	4.76	0.70
1.84	29.61	32.0	32.0	32.0	63.3	4.81	4.71	4.76	0.69
1.86	29.94	32.0	32.0	32.0	63.5	4.81	4.71	4.76	0.68
1.88	30.28	32.0	32.0	32.0	63.7	4.80	4.71	4.76	0.67
1.90	30.62	32.0	32.0	32.0	63.9	4.80	4.71	4.75	0.66
1.92	30.96	32.0	32.0	32.0	64.1	4.80	4.71	4.75	0.65
1.94	31.30	32.0	32.0	32.0	64.3	4.80	4.70	4.75	0.64
1.96	31.63	32.0	32.0	32.0	64.5	4.80	4.70	4.75	0.63
1.98	31.97	32.0	32.0	32.0	64.7	4.79	4.70	4.75	0.62

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.77	2.77	0.55	3.32	3.00	0.40	0.10
0.0	0.37	10.95	0.89	11.84	4.78	16.62	3.25	4.13	12.67
0.02	0.67	10.65	0.91	11.56	4.69	16.25	3.23	4.09	12.04
0.04	0.97	10.31	0.93	11.24	4.60	15.84	3.20	4.05	11.45
0.06	1.27	9.98	0.95	10.93	4.51	15.44	3.18	4.02	10.88
0.08	1.57	9.67	0.97	10.64	4.42	15.06	3.15	3.98	10.35
0.10	1.87	9.37	0.99	10.36	4.34	14.70	3.13	3.95	9.85
0.12	2.17	9.08	1.01	10.09	4.25	14.34	3.10	3.91	9.37
0.14	2.47	8.81	1.03	9.83	4.17	14.01	3.08	3.88	8.92
0.16	2.77	8.54	1.04	9.58	4.10	13.68	3.05	3.85	8.49
0.18	3.07	8.28	1.06	9.35	4.02	13.37	3.03	3.81	8.08
0.20	3.37	8.04	1.08	9.12	3.95	13.06	3.01	3.78	7.69
0.22	3.68	7.80	1.10	8.90	3.87	12.77	3.00	3.75	7.32
0.24	3.98	7.57	1.12	8.69	3.80	12.49	3.00	3.72	6.98
0.26	4.28	7.35	1.14	8.49	3.73	12.22	3.00	3.69	6.64
0.28	4.59	7.13	1.15	8.29	3.66	11.95	3.00	3.65	6.33
0.30	4.89	6.93	1.17	8.10	3.60	11.70	3.00	3.62	6.03
0.32	5.20	6.73	1.19	7.92	3.53	11.45	3.00	3.59	5.74
0.34	5.50	6.54	1.21	7.75	3.47	11.21	3.00	3.56	5.47
0.36	5.81	6.35	1.23	7.58	3.40	10.98	3.00	3.53	5.21
0.38	6.12	6.17	1.24	7.42	3.34	10.76	3.00	3.50	4.97
0.40	6.42	6.00	1.26	7.26	3.28	10.54	3.00	3.48	4.73
0.42	6.73	5.83	1.28	7.11	3.22	10.33	3.00	3.45	4.51
0.44	7.04	5.67	1.30	6.96	3.17	10.13	3.00	3.42	4.30
0.46	7.35	5.51	1.31	6.82	3.11	9.93	3.00	3.39	4.10
0.48	7.65	5.36	1.33	6.69	3.05	9.74	3.00	3.36	3.90
0.50	7.96	5.21	1.35	6.56	3.00	9.56	3.00	3.34	3.72

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.27	5.07	1.37	6.43	2.95	9.38	3.00	3.31	3.55
0.54	8.58	4.93	1.38	6.31	2.89	9.20	3.00	3.28	3.38
0.56	8.89	4.80	1.40	6.19	2.84	9.04	3.00	3.25	3.22
0.58	9.20	4.67	1.42	6.08	2.79	8.87	3.00	3.23	3.07
0.60	9.51	4.54	1.43	5.97	2.74	8.71	3.00	3.20	2.93
0.62	9.82	4.42	1.45	5.87	2.69	8.56	3.00	3.18	2.79
0.64	10.14	4.30	1.47	5.77	2.65	8.41	3.00	3.15	2.66
0.66	10.45	4.19	1.48	5.67	2.60	8.27	3.00	3.12	2.53
0.68	10.76	4.07	1.50	5.57	2.55	8.13	3.00	3.10	2.42
0.70	11.07	3.97	1.52	5.48	2.51	7.99	3.00	3.07	2.30
0.72	11.39	3.86	1.53	5.39	2.46	7.86	3.00	3.05	2.20
0.74	11.70	3.76	1.55	5.31	2.42	7.73	3.00	3.02	2.09
0.76	12.02	3.66	1.56	5.23	2.38	7.60	3.00	3.00	2.00
0.78	12.33	3.57	1.58	5.15	2.34	7.48	3.00	2.98	1.90
0.80	12.65	3.47	1.60	5.07	2.30	7.37	3.00	2.95	1.81
0.82	12.96	3.38	1.61	5.00	2.26	7.25	3.00	2.93	1.73
0.84	13.28	3.30	1.63	4.93	2.22	7.14	3.00	2.91	1.65
0.86	13.59	3.21	1.64	4.86	2.18	7.03	3.00	2.88	1.57
0.88	13.91	3.13	1.66	4.79	2.14	6.93	3.00	2.86	1.50
0.90	14.23	3.05	1.68	4.73	2.10	6.83	3.00	2.84	1.43
0.92	14.55	2.97	1.69	4.66	2.07	6.73	3.00	2.81	1.36
0.94	14.86	2.90	1.71	4.60	2.03	6.63	3.00	2.79	1.30
0.96	15.18	2.82	1.72	4.55	1.99	6.54	3.00	2.77	1.24
0.98	15.50	2.75	1.74	4.49	1.96	6.45	3.00	2.75	1.18
1.00	15.82	2.68	1.75	4.44	1.93	6.36	3.00	2.73	1.13
1.02	16.14	2.62	1.77	4.39	1.89	6.28	3.00	2.70	1.07

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	16.46	2.55	1.78	4.34	1.86	6.20	3.00	2.68	1.03
1.06	16.78	2.49	1.80	4.29	1.83	6.12	3.00	2.66	0.98
1.08	17.10	2.43	1.82	4.24	1.80	6.04	3.00	2.64	0.93
1.10	17.42	2.37	1.83	4.20	1.77	5.96	3.00	2.62	0.89
1.12	17.75	2.31	1.85	4.15	1.74	5.89	3.00	2.60	0.85
1.14	18.07	2.25	1.86	4.11	1.71	5.82	3.00	2.58	0.81
1.16	18.39	2.19	1.88	4.07	1.68	5.75	3.00	2.56	0.77
1.18	18.71	2.14	1.89	4.03	1.65	5.68	3.00	2.54	0.74
1.20	19.04	2.09	1.91	3.99	1.62	5.61	3.00	2.52	0.70
1.22	19.36	2.04	1.92	3.96	1.59	5.55	3.00	2.50	0.67
1.24	19.69	1.99	1.94	3.92	1.57	5.49	3.00	2.48	0.64
1.26	20.01	1.94	1.95	3.89	1.54	5.43	3.00	2.46	0.61
1.28	20.34	1.89	1.97	3.86	1.51	5.37	3.00	2.44	0.58
1.30	20.66	1.85	1.98	3.83	1.49	5.32	3.00	2.42	0.55
1.32	20.99	1.80	2.00	3.80	1.46	5.26	3.00	2.40	0.53
1.34	21.31	1.76	2.01	3.77	1.44	5.21	3.00	2.39	0.50
1.36	21.64	1.72	2.03	3.74	1.41	5.16	3.00	2.37	0.48
1.38	21.97	1.68	2.04	3.72	1.39	5.11	3.00	2.35	0.46
1.40	22.30	1.64	2.05	3.69	1.37	5.06	3.00	2.33	0.44
1.42	22.62	1.60	2.07	3.67	1.34	5.01	3.00	2.31	0.42
1.44	22.95	1.56	2.08	3.64	1.32	4.96	3.00	2.30	0.40
1.46	23.28	1.52	2.10	3.62	1.30	4.92	3.00	2.28	0.38
1.48	23.61	1.49	2.11	3.60	1.28	4.88	3.00	2.26	0.36
1.50	23.94	1.45	2.13	3.58	1.26	4.83	3.00	2.24	0.35
1.52	24.27	1.42	2.14	3.56	1.24	4.79	3.00	2.23	0.33
1.54	24.60	1.38	2.16	3.54	1.21	4.75	3.00	2.21	0.32

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	24.93	1.35	2.17	3.52	1.19	4.71	3.00	2.19	0.30
1.58	25.26	1.32	2.18	3.50	1.18	4.68	3.00	2.18	0.29
1.60	25.59	1.29	2.20	3.49	1.16	4.64	3.00	2.16	0.28
1.62	25.93	1.26	2.21	3.47	1.14	4.61	3.00	2.14	0.26
1.64	26.26	1.23	2.23	3.45	1.12	4.57	3.00	2.13	0.25
1.66	26.59	1.20	2.24	3.44	1.10	4.54	3.00	2.11	0.24
1.68	26.93	1.17	2.26	3.43	1.08	4.51	3.00	2.10	0.23
1.70	27.26	1.14	2.27	3.41	1.06	4.48	3.00	2.08	0.22
1.72	27.59	1.12	2.28	3.40	1.05	4.45	3.00	2.06	0.21
1.74	27.93	1.09	2.30	3.39	1.03	4.42	3.00	2.05	0.20
1.76	28.26	1.07	2.31	3.38	1.01	4.39	3.00	2.03	0.19
1.78	28.60	1.04	2.32	3.37	1.00	4.36	3.00	2.02	0.18
1.80	28.93	1.02	2.34	3.36	0.98	4.34	3.00	2.00	0.17
1.82	29.27	0.99	2.35	3.35	0.96	4.31	3.00	1.99	0.17
1.84	29.61	0.97	2.37	3.34	0.95	4.29	3.00	1.97	0.16
1.86	29.94	0.95	2.38	3.33	0.93	4.26	3.00	1.96	0.15
1.88	30.28	0.93	2.39	3.32	0.92	4.24	3.00	1.94	0.14
1.90	30.62	0.91	2.41	3.31	0.90	4.22	3.00	1.93	0.14
1.92	30.96	0.89	2.42	3.31	0.89	4.19	3.00	1.91	0.13
1.94	31.30	0.86	2.43	3.30	0.88	4.17	3.00	1.90	0.13
1.96	31.63	0.85	2.45	3.29	0.86	4.15	3.00	1.89	0.12
1.98	31.97	0.83	2.46	3.29	0.85	4.13	3.00	1.87	0.12

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, RUN FOR 1969 DO'S
SEASON :
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	12.83	0.37	0.0	10.35	0.37	0.0
MINIMUM DO, MG/L	4.79	31.97	1.98	4.70	31.97	1.98
FINAL DO, MG/L	6.38	12.65	0.80	6.15	12.65	0.80
DO DEFICIT						
INITIAL, MG/L	0.89	0.37	0.0	3.37	0.37	0.0
FINAL, MG/L	7.83	12.65	0.80	8.05	12.65	0.80
RIVER DISCHARGE						
INITIAL, CFS	45.76	0.37	0.0	45.76	0.37	0.0
FINAL, CFS	53.12	12.65	0.80	53.12	12.65	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	34.27	0.37	0.0	34.27	0.37	0.0
FINAL, DEG F	32.02	12.65	0.80	32.02	12.65	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	10.95	0.37	0.0	10.95	0.37	0.0
FINAL BOD, MG/L	3.47	12.65	0.80	3.48	12.65	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.05	0.37	0.0	0.05	0.37	0.0
FINAL BOD IN RIVER	1.56	12.65	0.80	1.63	12.65	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	4.78	0.37	0.0	4.78	0.37	0.0
FINAL BOD, MG/L	2.30	12.65	0.80	2.30	12.65	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	16.51	0.37	0.0	16.74	0.37	0.0
FINAL VALUE, MG/L	7.32	12.65	0.80	7.41	12.65	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	3.50	0.37	0.0	3.50	0.37	0.0
FINAL VALUE, MG/L	1.68	12.65	0.80	1.68	12.65	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.25	0.37	0.0	3.25	0.37	0.0
FINAL VALUE, MG/L	3.00	12.65	0.80	3.00	12.65	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.13	0.37	0.0	4.13	0.37	0.0
FINAL VALUE, MG/L	2.95	12.65	0.80	2.95	12.65	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	12.67	0.37	0.0	12.67	0.37	0.0
FINAL PERCENT	1.81	12.65	0.80	1.81	12.65	0.80

XXIV. APPENDIX G

A. Computer Results for 1970 Status Study, August, 2 Yr

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
4.55	70.00	75.00	0.0	40.00	0.080	0.0	12.00	12.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
82.00	67.00	115.00	80.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	50.00	2.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
25.00	3.00	105.00	70.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
82.00	67.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	2.00	3.00	3.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDOCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                    AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

      INPUT DATA FOR THIS ANALYSIS

      STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
      RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
      SEASON : AUGUST

 GAMMA1 =    0.80  , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
     OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
     CYCLE NO.  1
     BANK LOAD IS     50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR    0.0 LBS/DAY/MILE
          ADDITIONAL BANK LOAD DOWNSTREAM IS    2.00 LBS/DAY/MILE
     FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
          EFFLUENT Q =    7.04 CFS, RIVER Q =  25.00 CFS, TOTAL Q =  32.04 CFS
          CYCLE INCREMENT IS  0.0  CFS
     FOR ALGAE VARIATIONS, P-MINUS-R =    1.00 MG/L/HR
          CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	82.0	67.0		25.0	8.65	7.08		0.40
0.0	0.37	79.4	67.7	73.5	32.0	8.16	6.94	7.55	2.95
0.01	0.50	79.5	67.6	73.6	32.4	7.77	6.57	7.17	2.79
0.02	0.63	79.6	67.6	73.6	32.8	7.46	6.19	6.83	2.63
0.03	0.76	79.8	67.6	73.7	33.2	7.23	5.87	6.55	2.49
0.04	0.90	79.9	67.5	73.7	33.6	7.07	5.60	6.34	2.36
0.05	1.03	80.0	67.5	73.8	34.0	6.97	5.37	6.17	2.23
0.06	1.16	80.1	67.5	73.8	34.4	6.92	5.18	6.05	2.11
0.07	1.30	80.2	67.4	73.8	34.8	6.93	5.01	5.97	1.99
0.08	1.43	80.3	67.4	73.9	35.2	6.97	4.87	5.92	1.89
0.09	1.57	80.4	67.4	73.9	35.6	7.05	4.74	5.90	1.79
0.10	1.70	80.5	67.4	73.9	36.0	7.16	4.63	5.90	1.69
0.11	1.84	80.6	67.4	74.0	36.5	7.31	4.53	5.92	1.60
0.12	1.98	80.7	67.3	74.0	36.9	7.48	4.45	5.96	1.52
0.13	2.11	80.8	67.3	74.0	37.3	7.67	4.37	6.02	1.44
0.14	2.25	80.8	67.3	74.1	37.7	7.88	4.30	6.09	1.36
0.15	2.39	80.9	67.3	74.1	38.1	8.11	4.23	6.17	1.29
0.16	2.53	80.9	67.3	74.1	38.5	8.36	4.18	6.27	1.23
0.17	2.67	81.0	67.2	74.1	38.9	8.61	4.13	6.37	1.17
0.18	2.81	81.1	67.2	74.1	39.4	8.88	4.08	6.48	1.11
0.19	2.95	81.1	67.2	74.2	39.8	9.15	4.04	6.59	1.05
0.20	3.09	81.2	67.2	74.2	40.2	9.42	4.00	6.71	1.00
0.21	3.24	81.2	67.2	74.2	40.6	9.70	3.96	6.83	0.95
0.22	3.38	81.3	67.2	74.2	41.1	9.97	3.93	6.95	0.90
0.23	3.52	81.3	67.2	74.2	41.5	10.25	3.91	7.08	0.86
0.24	3.67	81.3	67.2	74.3	41.9	10.52	3.89	7.20	0.82
0.25	3.81	81.4	67.2	74.3	42.4	10.78	3.87	7.32	0.78

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	3.96	81.4	67.1	74.3	42.8	11.04	3.85	7.44	0.74
0.27	4.10	81.4	67.1	74.3	43.2	11.28	3.84	7.56	0.71
0.28	4.25	81.5	67.1	74.3	43.7	11.51	3.83	7.67	0.67
0.29	4.39	81.5	67.1	74.3	44.1	11.73	3.83	7.78	0.64
0.30	4.54	81.5	67.1	74.3	44.6	11.93	3.83	7.88	0.62
0.31	4.69	81.6	67.1	74.3	45.0	12.12	3.83	7.97	0.60
0.32	4.84	81.6	67.1	74.3	45.4	12.28	3.83	8.06	0.59
0.33	4.99	81.6	67.1	74.4	45.9	12.43	3.84	8.14	0.57
0.34	5.14	81.6	67.1	74.4	46.3	12.56	3.85	8.20	0.56
0.35	5.29	81.6	67.1	74.4	46.8	12.67	3.86	8.27	0.54
0.36	5.44	81.7	67.1	74.4	47.2	12.76	3.88	8.32	0.53
0.37	5.59	81.7	67.1	74.4	47.7	12.82	3.90	8.36	0.52
0.38	5.74	81.7	67.1	74.4	48.1	12.87	3.92	8.39	0.51
0.39	5.89	81.7	67.1	74.4	48.6	12.89	3.95	8.42	0.50
0.40	6.04	81.7	67.1	74.4	49.1	12.89	3.98	8.43	0.49
0.41	6.20	81.8	67.1	74.4	49.5	12.87	4.01	8.44	0.48
0.42	6.35	81.8	67.1	74.4	50.0	12.83	4.04	8.44	0.47
0.43	6.50	81.8	67.1	74.4	50.4	12.77	4.08	8.43	0.46
0.44	6.66	81.8	67.1	74.4	50.9	12.69	4.13	8.41	0.45
0.45	6.81	81.8	67.0	74.4	51.4	12.59	4.17	8.38	0.44
0.46	6.97	81.8	67.0	74.4	51.8	12.48	4.23	8.35	0.43
0.47	7.13	81.8	67.0	74.4	52.3	12.36	4.28	8.32	0.42
0.48	7.28	81.8	67.0	74.4	52.8	12.22	4.34	8.28	0.42
0.49	7.44	81.8	67.0	74.4	53.3	12.06	4.40	8.23	0.41
0.50	7.60	81.9	67.0	74.4	53.7	11.90	4.47	8.19	0.40
0.51	7.76	81.9	67.0	74.4	54.2	11.73	4.54	8.14	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	7.92	81.9	67.0	74.5	54.7	11.56	4.62	8.09	0.40
0.53	8.08	81.9	67.0	74.5	55.2	11.38	4.70	8.04	0.40
0.54	8.24	81.9	67.0	74.5	55.6	11.20	4.78	7.99	0.40
0.55	8.40	81.9	67.0	74.5	56.1	11.02	4.87	7.95	0.40
0.56	8.56	81.9	67.0	74.5	56.6	10.84	4.96	7.90	0.40
0.57	8.72	81.9	67.0	74.5	57.1	10.67	5.05	7.86	0.40
0.58	8.88	81.9	67.0	74.5	57.6	10.50	5.14	7.82	0.40
0.59	9.04	81.9	67.0	74.5	58.1	10.34	5.23	7.79	0.40
0.60	9.21	81.9	67.0	74.5	58.6	10.19	5.32	7.76	0.40
0.61	9.37	81.9	67.0	74.5	59.0	10.05	5.41	7.73	0.40
0.62	9.54	81.9	67.0	74.5	59.5	9.92	5.49	7.71	0.40
0.63	9.70	81.9	67.0	74.5	60.0	9.81	5.57	7.69	0.40
0.64	9.87	81.9	67.0	74.5	60.5	9.71	5.64	7.67	0.40
0.65	10.03	81.9	67.0	74.5	61.0	9.63	5.70	7.66	0.40
0.66	10.20	81.9	67.0	74.5	61.5	9.55	5.75	7.65	0.40
0.67	10.36	81.9	67.0	74.5	62.0	9.49	5.80	7.65	0.40
0.68	10.53	81.9	67.0	74.5	62.5	9.44	5.85	7.64	0.40
0.69	10.70	82.0	67.0	74.5	63.0	9.39	5.89	7.64	0.40
0.70	10.87	82.0	67.0	74.5	63.5	9.36	5.93	7.64	0.40
0.71	11.04	82.0	67.0	74.5	64.0	9.32	5.96	7.64	0.40
0.72	11.20	82.0	67.0	74.5	64.5	9.30	5.99	7.64	0.40
0.73	11.37	82.0	67.0	74.5	65.1	9.27	6.02	7.65	0.40
0.74	11.54	82.0	67.0	74.5	65.6	9.25	6.04	7.65	0.40
0.75	11.72	82.0	67.0	74.5	66.1	9.23	6.07	7.65	0.40
0.76	11.89	82.0	67.0	74.5	66.6	9.22	6.09	7.65	0.40
0.77	12.06	82.0	67.0	74.5	67.1	9.21	6.11	7.66	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	12.23	82.0	67.0	74.5	67.6	9.20	6.12	7.66	0.40
0.79	12.40	82.0	67.0	74.5	68.1	9.19	6.14	7.67	0.40
0.80	12.58	82.0	67.0	74.5	68.7	9.18	6.15	7.67	0.40
0.81	12.75	82.0	67.0	74.5	69.2	9.18	6.17	7.67	0.40
0.82	12.92	82.0	67.0	74.5	69.7	9.17	6.18	7.68	0.40
0.83	13.10	82.0	67.0	74.5	70.2	9.17	6.19	7.68	0.40
0.84	13.27	82.0	67.0	74.5	70.8	9.17	6.20	7.68	0.40
0.85	13.45	82.0	67.0	74.5	71.3	9.16	6.21	7.69	0.40
0.86	13.63	82.0	67.0	74.5	71.8	9.16	6.22	7.69	0.40
0.87	13.80	82.0	67.0	74.5	72.3	9.16	6.23	7.70	0.40
0.88	13.98	82.0	67.0	74.5	72.9	9.16	6.24	7.70	0.40
0.89	14.16	82.0	67.0	74.5	73.4	9.16	6.24	7.70	0.40
0.90	14.34	82.0	67.0	74.5	73.9	9.16	6.25	7.71	0.40
0.91	14.51	82.0	67.0	74.5	74.5	9.16	6.26	7.71	0.40
0.92	14.69	82.0	67.0	74.5	75.0	9.16	6.26	7.71	0.40
0.93	14.87	82.0	67.0	74.5	75.6	9.16	6.27	7.71	0.40
0.94	15.05	82.0	67.0	74.5	76.1	9.16	6.27	7.72	0.40
0.95	15.23	82.0	67.0	74.5	76.6	9.16	6.28	7.72	0.40
0.96	15.41	82.0	67.0	74.5	77.2	9.16	6.28	7.72	0.40
0.97	15.60	82.0	67.0	74.5	77.7	9.16	6.29	7.72	0.40
0.98	15.78	82.0	67.0	74.5	78.3	9.16	6.29	7.73	0.40
0.99	15.96	82.0	67.0	74.5	78.8	9.17	6.29	7.73	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	1.16	3.16	0.55	3.71	3.00	0.40	0.10
0.0	0.37	13.25	1.53	14.78	4.04	18.82	4.98	5.81	22.06
0.01	0.50	12.67	1.53	14.21	3.81	18.02	4.80	5.66	20.32
0.02	0.63	12.02	1.52	13.55	3.60	17.15	4.63	5.51	18.72
0.03	0.76	11.41	1.51	12.92	3.41	16.33	4.46	5.37	17.25
0.04	0.90	10.84	1.50	12.34	3.22	15.56	4.30	5.23	15.89
0.05	1.03	10.30	1.49	11.79	3.05	14.84	4.14	5.09	14.65
0.06	1.16	9.79	1.49	11.28	2.88	14.16	3.99	4.96	13.50
0.07	1.30	9.31	1.48	10.79	2.73	13.52	3.85	4.83	12.45
0.08	1.43	8.86	1.47	10.33	2.58	12.92	3.71	4.71	11.47
0.09	1.57	8.44	1.47	9.90	2.44	12.35	3.58	4.59	10.58
0.10	1.70	8.03	1.46	9.50	2.31	11.81	3.45	4.47	9.76
0.11	1.84	7.66	1.46	9.12	2.19	11.31	3.33	4.36	9.00
0.12	1.98	7.30	1.45	8.75	2.08	10.83	3.28	4.25	8.31
0.13	2.11	6.96	1.45	8.41	1.97	10.38	3.23	4.14	7.67
0.14	2.25	6.64	1.45	8.09	1.87	9.96	3.18	4.04	7.08
0.15	2.39	6.34	1.45	7.79	1.77	9.56	3.14	3.94	6.53
0.16	2.53	6.05	1.44	7.50	1.68	9.18	3.10	3.84	6.03
0.17	2.67	5.78	1.44	7.23	1.59	8.82	3.05	3.75	5.57
0.18	2.81	5.53	1.44	6.97	1.51	8.48	3.01	3.65	5.15
0.19	2.95	5.29	1.44	6.72	1.44	8.16	3.00	3.56	4.76
0.20	3.09	5.06	1.44	6.49	1.37	7.86	3.00	3.48	4.40
0.21	3.24	4.84	1.44	6.27	1.30	7.57	3.00	3.39	4.06
0.22	3.38	4.63	1.44	6.07	1.23	7.30	3.00	3.31	3.76
0.23	3.52	4.43	1.44	5.87	1.17	7.04	3.00	3.23	3.47
0.24	3.67	4.25	1.44	5.68	1.12	6.80	3.00	3.15	3.21
0.25	3.81	4.07	1.44	5.51	1.06	6.57	3.00	3.08	2.97

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	3.96	3.90	1.44	5.34	1.01	6.35	3.00	3.00	2.75
0.27	4.10	3.74	1.44	5.18	0.97	6.14	3.00	2.93	2.55
0.28	4.25	3.59	1.44	5.02	0.92	5.95	3.00	2.86	2.36
0.29	4.39	3.44	1.44	4.88	0.88	5.76	3.00	2.79	2.19
0.30	4.54	3.30	1.44	4.74	0.84	5.58	3.00	2.72	2.03
0.31	4.69	3.17	1.44	4.61	0.80	5.41	3.00	2.66	1.88
0.32	4.84	3.04	1.44	4.49	0.76	5.25	3.00	2.60	1.74
0.33	4.99	2.92	1.44	4.37	0.73	5.10	3.00	2.54	1.61
0.34	5.14	2.81	1.45	4.26	0.70	4.95	3.00	2.48	1.50
0.35	5.29	2.70	1.45	4.15	0.67	4.82	3.00	2.42	1.39
0.36	5.44	2.60	1.45	4.05	0.64	4.69	3.00	2.37	1.29
0.37	5.59	2.50	1.45	3.95	0.61	4.56	3.00	2.31	1.20
0.38	5.74	2.40	1.45	3.85	0.59	4.44	3.00	2.26	1.11
0.39	5.89	2.31	1.46	3.77	0.56	4.33	3.00	2.21	1.03
0.40	6.04	2.22	1.46	3.68	0.54	4.22	3.00	2.16	0.96
0.41	6.20	2.14	1.46	3.60	0.52	4.12	3.00	2.11	0.89
0.42	6.35	2.06	1.46	3.52	0.50	4.02	3.00	2.07	0.83
0.43	6.50	1.98	1.47	3.45	0.48	3.92	3.00	2.02	0.77
0.44	6.66	1.91	1.47	3.38	0.46	3.84	3.00	1.97	0.72
0.45	6.81	1.84	1.47	3.31	0.44	3.75	3.00	1.93	0.67
0.46	6.97	1.77	1.47	3.24	0.42	3.67	3.00	1.89	0.62
0.47	7.13	1.71	1.47	3.18	0.41	3.59	3.00	1.85	0.58
0.48	7.28	1.65	1.48	3.12	0.39	3.52	3.00	1.81	0.54
0.49	7.44	1.59	1.48	3.07	0.38	3.45	3.00	1.77	0.50
0.50	7.60	1.53	1.48	3.01	0.37	3.38	3.00	1.73	0.47
0.51	7.76	1.48	1.48	2.96	0.35	3.31	3.00	1.69	0.43

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER					NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
		EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L			
0.52	7.92	1.42	1.49	2.91	0.34	3.25	3.00	1.66	0.40
0.53	8.08	1.37	1.49	2.86	0.33	3.19	3.00	1.62	0.38
0.54	8.24	1.33	1.49	2.82	0.32	3.14	3.00	1.59	0.35
0.55	8.40	1.28	1.49	2.77	0.31	3.08	3.00	1.55	0.33
0.56	8.56	1.24	1.50	2.73	0.30	3.03	3.00	1.52	0.31
0.57	8.72	1.19	1.50	2.69	0.29	2.98	3.00	1.49	0.29
0.58	8.88	1.15	1.50	2.65	0.28	2.93	3.00	1.46	0.27
0.59	9.04	1.11	1.51	2.62	0.27	2.89	3.00	1.43	0.26
0.60	9.21	1.07	1.51	2.58	0.26	2.84	3.00	1.40	0.24
0.61	9.37	1.04	1.51	2.55	0.25	2.80	3.00	1.37	0.23
0.62	9.54	1.00	1.51	2.52	0.24	2.76	3.00	1.34	0.22
0.63	9.70	0.97	1.52	2.48	0.24	2.72	3.00	1.31	0.21
0.64	9.87	0.94	1.52	2.45	0.23	2.69	3.00	1.29	0.20
0.65	10.03	0.91	1.52	2.43	0.22	2.65	3.00	1.26	0.19
0.66	10.20	0.88	1.52	2.40	0.22	2.62	3.00	1.24	0.18
0.67	10.36	0.85	1.52	2.37	0.21	2.58	3.00	1.21	0.17
0.68	10.53	0.82	1.53	2.35	0.21	2.55	3.00	1.19	0.17
0.69	10.70	0.79	1.53	2.32	0.20	2.52	3.00	1.17	0.16
0.70	10.87	0.77	1.53	2.30	0.20	2.49	3.00	1.14	0.15
0.71	11.04	0.74	1.53	2.27	0.19	2.47	3.00	1.12	0.15
0.72	11.20	0.72	1.54	2.25	0.19	2.44	3.00	1.10	0.14
0.73	11.37	0.69	1.54	2.23	0.18	2.41	3.00	1.08	0.14
0.74	11.54	0.67	1.54	2.21	0.18	2.39	3.00	1.06	0.13
0.75	11.72	0.65	1.54	2.19	0.17	2.36	3.00	1.04	0.13
0.76	11.89	0.63	1.55	2.17	0.17	2.34	3.00	1.02	0.12
0.77	12.06	0.61	1.55	2.16	0.17	2.32	3.00	1.00	0.12

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

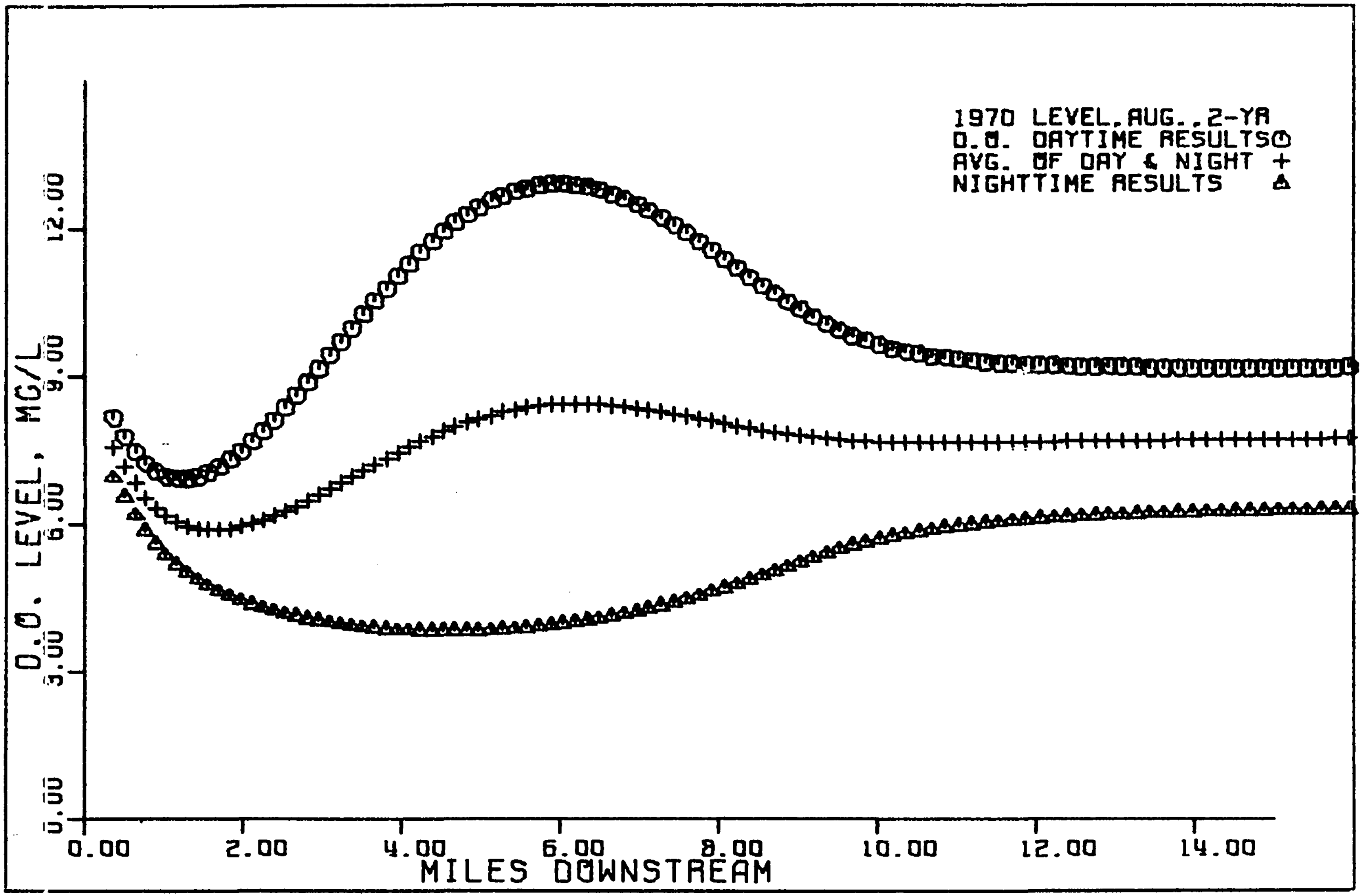
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	12.23	0.59	1.55	2.14	0.16	2.30	3.00	0.98	0.11
0.79	12.40	0.57	1.55	2.12	0.16	2.28	3.00	0.96	0.11
0.80	12.58	0.55	1.55	2.11	0.15	2.26	3.00	0.94	0.11
0.81	12.75	0.53	1.56	2.09	0.15	2.24	3.00	0.92	0.10
0.82	12.92	0.52	1.56	2.07	0.15	2.22	3.00	0.91	0.10
0.83	13.10	0.50	1.56	2.06	0.15	2.21	3.00	0.89	0.10
0.84	13.27	0.49	1.56	2.05	0.14	2.19	3.00	0.87	0.10
0.85	13.45	0.47	1.56	2.03	0.14	2.17	3.00	0.86	0.10
0.86	13.63	0.46	1.57	2.02	0.14	2.16	3.00	0.84	0.10
0.87	13.80	0.44	1.57	2.01	0.13	2.14	3.00	0.83	0.10
0.88	13.98	0.43	1.57	2.00	0.13	2.13	3.00	0.81	0.10
0.89	14.16	0.41	1.57	1.98	0.13	2.11	3.00	0.80	0.10
0.90	14.34	0.40	1.57	1.97	0.13	2.10	3.00	0.78	0.10
0.91	14.51	0.39	1.57	1.96	0.13	2.09	3.00	0.77	0.10
0.92	14.69	0.38	1.58	1.95	0.12	2.08	3.00	0.76	0.10
0.93	14.87	0.37	1.58	1.94	0.12	2.06	3.00	0.74	0.10
0.94	15.05	0.35	1.58	1.93	0.12	2.05	3.00	0.73	0.10
0.95	15.23	0.34	1.58	1.92	0.12	2.04	3.00	0.72	0.10
0.96	15.41	0.33	1.58	1.92	0.12	2.03	3.00	0.71	0.10
0.97	15.60	0.32	1.58	1.91	0.11	2.02	3.00	0.69	0.10
0.98	15.78	0.31	1.59	1.90	0.11	2.01	3.00	0.68	0.10
0.99	15.96	0.30	1.59	1.89	0.11	2.00	3.00	0.67	0.10

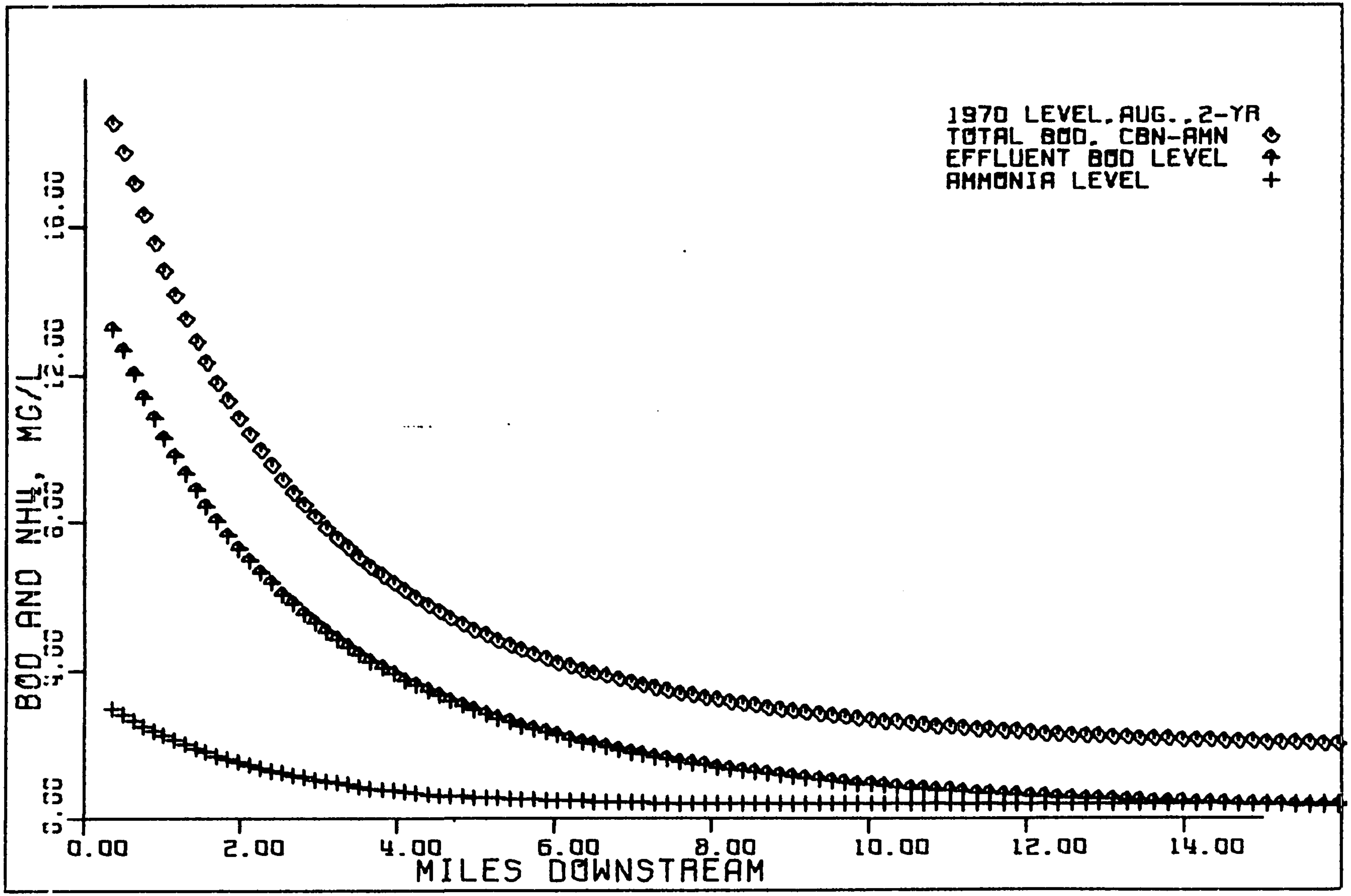
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.16	0.37	0.0	6.94	0.37	0.0
MINIMUM DO, MG/L	6.92	1.16	0.06	3.83	4.54	0.30
FINAL DO, MG/L	9.18	12.58	0.80	6.15	12.58	0.80
DO DEFICIT						
INITIAL, MG/L	-0.43	0.37	0.0	1.85	0.37	0.0
FINAL, MG/L	-1.66	12.58	0.80	2.70	12.58	0.80
RIVER DISCHARGE						
INITIAL, CFS	32.04	0.37	0.0	32.04	0.37	0.0
FINAL, CFS	68.66	12.58	0.80	68.66	12.58	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	79.36	0.37	0.0	67.66	0.37	0.0
FINAL, DEG F	81.97	12.58	0.80	67.01	12.58	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	13.25	0.37	0.0	13.25	0.37	0.0
FINAL BOD, MG/L	0.36	12.58	0.80	0.74	12.58	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.38	12.58	0.80	1.72	12.58	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	4.04	0.37	0.0	4.04	0.37	0.0
FINAL BOD, MG/L	0.08	12.58	0.80	0.23	12.58	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	18.45	0.37	0.0	19.19	0.37	0.0
FINAL VALUE, MG/L	1.82	12.58	0.80	2.70	12.58	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	2.95	0.37	0.0	2.95	0.37	0.0
FINAL VALUE, MG/L	0.40	12.58	0.80	0.40	12.58	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.98	0.37	0.0	4.98	0.37	0.0
FINAL VALUE, MG/L	3.00	12.58	0.80	3.00	12.58	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	5.81	0.37	0.0	5.81	0.37	0.0
FINAL VALUE, MG/L	0.63	12.58	0.80	1.26	12.58	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	22.06	0.37	0.0	22.06	0.37	0.0
FINAL PERCENT	0.10	12.58	0.80	0.11	12.58	0.80


1970 LEVEL.AUG..2-YR
D.O. DAYTIME RESULTS ⊙
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


1970 LEVEL.AUG..2-YR
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

B. Computer Results for 1970 Status Study, September, 2 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
4.55	65.00	75.00	0.0	40.00	0.080	0.0	15.00	10.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
77.00	62.00	120.00	75.00	2.50	0.140	0.0	0.40	3.00	0.40	0.10	60.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
12.00	1.50	110.00	65.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
77.00	62.00	2.500	0.0	0.0	3.000	0.100	0.40	1.20	1.60	2.50	2.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 60.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 3.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 7.04 CFS, RIVER Q = 12.00 CFS, TOTAL Q = 19.04 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 1.20 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	77.0	62.0		12.0	9.52	7.04		0.40
0.0	0.37	72.6	63.1	67.8	19.0	8.51	6.95	7.73	5.80
0.01	0.48	72.8	63.0	67.9	19.2	7.93	6.19	7.06	5.55
0.02	0.59	73.0	63.0	68.0	19.4	7.44	5.42	6.43	5.32
0.03	0.69	73.3	62.9	68.1	19.5	7.06	4.76	5.91	5.09
0.04	0.80	73.5	62.9	68.2	19.7	6.76	4.19	5.47	4.87
0.05	0.91	73.7	62.8	68.3	19.9	6.54	3.70	5.12	4.67
0.06	1.02	73.9	62.8	68.3	20.0	6.39	3.27	4.83	4.47
0.07	1.13	74.0	62.7	68.4	20.2	6.30	2.90	4.60	4.28
0.08	1.24	74.2	62.7	68.4	20.3	6.27	2.59	4.43	4.09
0.09	1.35	74.4	62.7	68.5	20.5	6.29	2.31	4.30	3.92
0.10	1.46	74.5	62.6	68.6	20.7	6.36	2.07	4.21	3.75
0.11	1.57	74.6	62.6	68.6	20.8	6.47	1.86	4.16	3.59
0.12	1.68	74.8	62.6	68.7	21.0	6.61	1.68	4.15	3.44
0.13	1.79	74.9	62.5	68.7	21.2	6.79	1.55	4.17	3.30
0.14	1.91	75.0	62.5	68.8	21.3	6.99	1.43	4.21	3.17
0.15	2.02	75.1	62.5	68.8	21.5	7.22	1.34	4.28	3.04
0.16	2.13	75.2	62.4	68.9	21.7	7.47	1.27	4.37	2.93
0.17	2.24	75.3	62.4	68.9	21.9	7.75	1.21	4.48	2.81
0.18	2.36	75.4	62.4	68.9	22.0	8.03	1.15	4.59	2.71
0.19	2.47	75.5	62.4	68.9	22.2	8.33	1.11	4.72	2.61
0.20	2.58	75.6	62.4	69.0	22.4	8.65	1.07	4.86	2.51
0.21	2.70	75.7	62.3	69.0	22.5	8.97	1.04	5.01	2.42
0.22	2.81	75.7	62.3	69.0	22.7	9.30	1.02	5.16	2.33
0.23	2.93	75.8	62.3	69.1	22.9	9.63	0.99	5.31	2.25
0.24	3.04	75.9	62.3	69.1	23.1	9.97	0.97	5.47	2.17
0.25	3.16	75.9	62.3	69.1	23.2	10.31	0.96	5.63	2.09

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	3.28	76.0	62.2	69.1	23.4	10.64	0.95	5.80	2.02
0.27	3.39	76.1	62.2	69.1	23.6	10.98	0.94	5.96	1.95
0.28	3.51	76.1	62.2	69.2	23.7	11.31	0.93	6.12	1.89
0.29	3.62	76.2	62.2	69.2	23.9	11.63	0.92	6.28	1.82
0.30	3.74	76.2	62.2	69.2	24.1	11.94	0.92	6.43	1.76
0.31	3.86	76.3	62.2	69.2	24.3	12.25	0.92	6.58	1.70
0.32	3.98	76.3	62.2	69.2	24.5	12.54	0.92	6.73	1.65
0.33	4.09	76.3	62.2	69.3	24.6	12.82	0.92	6.87	1.59
0.34	4.21	76.4	62.2	69.3	24.8	13.09	0.93	7.01	1.54
0.35	4.33	76.4	62.1	69.3	25.0	13.34	0.93	7.14	1.49
0.36	4.45	76.4	62.1	69.3	25.2	13.58	0.94	7.26	1.45
0.37	4.57	76.5	62.1	69.3	25.3	13.80	0.95	7.37	1.40
0.38	4.69	76.5	62.1	69.3	25.5	14.00	0.96	7.48	1.36
0.39	4.81	76.5	62.1	69.3	25.7	14.18	0.97	7.58	1.31
0.40	4.93	76.6	62.1	69.3	25.9	14.34	0.99	7.67	1.27
0.41	5.05	76.6	62.1	69.3	26.1	14.49	1.00	7.75	1.23
0.42	5.17	76.6	62.1	69.4	26.2	14.61	1.02	7.82	1.20
0.43	5.29	76.6	62.1	69.4	26.4	14.71	1.04	7.88	1.16
0.44	5.41	76.6	62.1	69.4	26.6	14.79	1.06	7.93	1.12
0.45	5.54	76.7	62.1	69.4	26.8	14.85	1.09	7.97	1.09
0.46	5.66	76.7	62.1	69.4	27.0	14.89	1.11	8.00	1.06
0.47	5.78	76.7	62.1	69.4	27.2	14.91	1.14	8.02	1.03
0.48	5.90	76.7	62.1	69.4	27.3	14.91	1.17	8.04	1.00
0.49	6.03	76.7	62.1	69.4	27.5	14.89	1.20	8.04	0.97
0.50	6.15	76.7	62.1	69.4	27.7	14.85	1.23	8.04	0.94
0.51	6.27	76.8	62.1	69.4	27.9	14.79	1.27	8.03	0.92

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	6.40	76.8	62.1	69.4	28.1	14.71	1.30	8.01	0.90
0.53	6.52	76.8	62.1	69.4	28.3	14.61	1.34	7.98	0.89
0.54	6.65	76.8	62.0	69.4	28.5	14.50	1.39	7.94	0.87
0.55	6.77	76.8	62.0	69.4	28.6	14.38	1.43	7.90	0.85
0.56	6.90	76.8	62.0	69.4	28.8	14.24	1.48	7.86	0.83
0.57	7.02	76.8	62.0	69.4	29.0	14.08	1.54	7.81	0.82
0.58	7.15	76.8	62.0	69.4	29.2	13.92	1.59	7.76	0.80
0.59	7.28	76.9	62.0	69.4	29.4	13.74	1.65	7.70	0.78
0.60	7.40	76.9	62.0	69.4	29.6	13.56	1.72	7.64	0.77
0.61	7.53	76.9	62.0	69.5	29.8	13.37	1.79	7.58	0.75
0.62	7.66	76.9	62.0	69.5	30.0	13.17	1.86	7.52	0.74
0.63	7.78	76.9	62.0	69.5	30.2	12.97	1.94	7.45	0.72
0.64	7.91	76.9	62.0	69.5	30.4	12.77	2.02	7.39	0.70
0.65	8.04	76.9	62.0	69.5	30.5	12.57	2.10	7.33	0.69
0.66	8.17	76.9	62.0	69.5	30.7	12.37	2.19	7.28	0.67
0.67	8.30	76.9	62.0	69.5	30.9	12.17	2.29	7.23	0.66
0.68	8.43	76.9	62.0	69.5	31.1	11.97	2.38	7.18	0.65
0.69	8.55	76.9	62.0	69.5	31.3	11.78	2.49	7.13	0.63
0.70	8.68	76.9	62.0	69.5	31.5	11.60	2.59	7.09	0.62
0.71	8.81	76.9	62.0	69.5	31.7	11.42	2.70	7.06	0.61
0.72	8.94	76.9	62.0	69.5	31.9	11.26	2.80	7.03	0.60
0.73	9.07	76.9	62.0	69.5	32.1	11.10	2.91	7.01	0.58
0.74	9.21	76.9	62.0	69.5	32.3	10.96	3.01	6.98	0.57
0.75	9.34	76.9	62.0	69.5	32.5	10.83	3.11	6.97	0.56
0.76	9.47	76.9	62.0	69.5	32.7	10.72	3.20	6.96	0.55
0.77	9.60	76.9	62.0	69.5	32.9	10.62	3.28	6.95	0.54

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	9.73	76.9	62.0	69.5	33.1	10.53	3.35	6.94	0.53
0.79	9.86	77.0	62.0	69.5	33.3	10.45	3.42	6.94	0.52
0.80	10.00	77.0	62.0	69.5	33.5	10.39	3.49	6.94	0.51
0.81	10.13	77.0	62.0	69.5	33.7	10.33	3.54	6.94	0.50
0.82	10.26	77.0	62.0	69.5	33.9	10.29	3.60	6.94	0.49
0.83	10.39	77.0	62.0	69.5	34.1	10.24	3.65	6.94	0.49
0.84	10.53	77.0	62.0	69.5	34.3	10.21	3.69	6.95	0.48
0.85	10.66	77.0	62.0	69.5	34.5	10.18	3.73	6.95	0.47
0.86	10.80	77.0	62.0	69.5	34.7	10.15	3.77	6.96	0.46
0.87	10.93	77.0	62.0	69.5	34.9	10.13	3.80	6.97	0.46
0.88	11.07	77.0	62.0	69.5	35.1	10.11	3.84	6.97	0.45
0.89	11.20	77.0	62.0	69.5	35.3	10.09	3.87	6.98	0.44
0.90	11.34	77.0	62.0	69.5	35.5	10.08	3.89	6.99	0.43
0.91	11.47	77.0	62.0	69.5	35.7	10.07	3.92	6.99	0.43
0.92	11.61	77.0	62.0	69.5	35.9	10.06	3.94	7.00	0.42
0.93	11.74	77.0	62.0	69.5	36.1	10.05	3.97	7.01	0.42
0.94	11.88	77.0	62.0	69.5	36.3	10.04	3.99	7.02	0.41
0.95	12.02	77.0	62.0	69.5	36.5	10.04	4.01	7.02	0.40
0.96	12.16	77.0	62.0	69.5	36.7	10.03	4.03	7.03	0.40
0.97	12.29	77.0	62.0	69.5	36.9	10.03	4.04	7.04	0.40
0.98	12.43	77.0	62.0	69.5	37.1	10.03	4.06	7.04	0.40
0.99	12.57	77.0	62.0	69.5	37.3	10.03	4.07	7.05	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER					NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
		EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L			
0.0	0.0	2.50	1.72	4.22	0.55	4.77	3.00	0.40	0.10
0.0	0.37	21.25	2.29	23.55	7.93	31.48	5.59	9.50	37.05
0.01	0.48	20.43	2.29	22.71	7.60	30.31	5.47	9.31	34.62
0.02	0.59	19.48	2.26	21.73	7.27	29.01	5.36	9.13	32.34
0.03	0.69	18.58	2.23	20.81	6.96	27.77	5.25	8.95	30.22
0.04	0.80	17.72	2.21	19.93	6.67	26.60	5.13	8.78	28.23
0.05	0.91	16.92	2.18	19.10	6.38	25.48	5.02	8.60	26.37
0.06	1.02	16.15	2.16	18.31	6.11	24.42	4.91	8.43	24.64
0.07	1.13	15.43	2.14	17.57	5.85	23.42	4.80	8.27	23.01
0.08	1.24	14.74	2.12	16.86	5.60	22.46	4.69	8.11	21.50
0.09	1.35	14.09	2.11	16.19	5.36	21.56	4.58	7.95	20.08
0.10	1.46	13.47	2.09	15.56	5.13	20.69	4.47	7.79	18.76
0.11	1.57	12.88	2.08	14.96	4.91	19.87	4.37	7.64	17.53
0.12	1.68	12.33	2.06	14.39	4.71	19.10	4.26	7.49	16.37
0.13	1.79	11.80	2.05	13.85	4.52	18.37	4.15	7.34	15.30
0.14	1.91	11.30	2.04	13.34	4.33	17.67	4.04	7.20	14.29
0.15	2.02	10.82	2.03	12.85	4.16	17.01	3.93	7.06	13.36
0.16	2.13	10.37	2.02	12.39	4.00	16.39	3.82	6.92	12.48
0.17	2.24	9.94	2.01	11.95	3.85	15.80	3.72	6.79	11.67
0.18	2.36	9.53	2.01	11.53	3.70	15.23	3.61	6.66	10.90
0.19	2.47	9.13	2.00	11.13	3.57	14.70	3.51	6.53	10.19
0.20	2.58	8.76	1.99	10.76	3.43	14.19	3.41	6.40	9.53
0.21	2.70	8.41	1.99	10.40	3.31	13.71	3.31	6.28	8.91
0.22	2.81	8.07	1.98	10.06	3.19	13.25	3.26	6.16	8.33
0.23	2.93	7.75	1.98	9.73	3.09	12.81	3.21	6.04	7.79
0.24	3.04	7.44	1.98	9.42	2.97	12.39	3.17	5.92	7.29
0.25	3.16	7.15	1.97	9.13	2.86	11.99	3.13	5.81	6.82

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	3.28	6.87	1.97	8.85	2.76	11.61	3.08	5.70	6.38
0.27	3.39	6.61	1.97	8.58	2.67	11.25	3.05	5.59	5.97
0.28	3.51	6.35	1.97	8.32	2.58	10.90	3.01	5.48	5.59
0.29	3.62	6.11	1.97	8.08	2.49	10.57	3.00	5.38	5.23
0.30	3.74	5.88	1.97	7.85	2.41	10.26	3.00	5.28	4.89
0.31	3.86	5.66	1.97	7.63	2.33	9.96	3.00	5.18	4.58
0.32	3.98	5.45	1.97	7.41	2.25	9.67	3.00	5.08	4.29
0.33	4.09	5.24	1.97	7.21	2.18	9.39	3.00	4.98	4.02
0.34	4.21	5.05	1.97	7.02	2.11	9.13	3.00	4.89	3.76
0.35	4.33	4.86	1.97	6.84	2.04	8.88	3.00	4.80	3.53
0.36	4.45	4.69	1.98	6.66	1.98	8.64	3.00	4.71	3.30
0.37	4.57	4.52	1.98	6.49	1.92	8.41	3.00	4.62	3.10
0.38	4.69	4.35	1.98	6.33	1.86	8.19	3.00	4.54	2.90
0.39	4.81	4.20	1.98	6.18	1.80	7.98	3.00	4.45	2.72
0.40	4.93	4.05	1.99	6.03	1.74	7.78	3.00	4.37	2.55
0.41	5.05	3.90	1.99	5.89	1.69	7.58	3.00	4.29	2.39
0.42	5.17	3.77	1.99	5.76	1.64	7.40	3.00	4.21	2.24
0.43	5.29	3.63	2.00	5.63	1.59	7.22	3.00	4.13	2.10
0.44	5.41	3.51	2.00	5.51	1.54	7.05	3.00	4.06	1.97
0.45	5.54	3.39	2.01	5.39	1.49	6.88	3.00	3.98	1.85
0.46	5.66	3.27	2.01	5.28	1.45	6.73	3.00	3.91	1.74
0.47	5.78	3.16	2.01	5.17	1.40	6.58	3.00	3.84	1.63
0.48	5.90	3.05	2.02	5.07	1.36	6.43	3.00	3.77	1.53
0.49	6.03	2.95	2.02	4.97	1.32	6.29	3.00	3.70	1.44
0.50	6.15	2.85	2.03	4.88	1.28	6.16	3.00	3.63	1.35
0.51	6.27	2.75	2.03	4.78	1.24	6.03	3.00	3.57	1.27

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	6.40	2.66	2.04	4.70	1.21	5.90	3.00	3.50	1.19
0.53	6.52	2.57	2.05	4.62	1.17	5.78	3.00	3.44	1.12
0.54	6.65	2.48	2.05	4.54	1.13	5.67	3.00	3.38	1.05
0.55	6.77	2.40	2.06	4.46	1.10	5.56	3.00	3.32	0.99
0.56	6.90	2.32	2.06	4.39	1.07	5.45	3.00	3.26	0.93
0.57	7.02	2.25	2.07	4.32	1.03	5.35	3.00	3.20	0.88
0.58	7.15	2.17	2.07	4.25	1.00	5.25	3.00	3.15	0.82
0.59	7.28	2.10	2.08	4.18	0.97	5.16	3.00	3.09	0.77
0.60	7.40	2.04	2.09	4.12	0.94	5.06	3.00	3.04	0.73
0.61	7.53	1.97	2.09	4.06	0.91	4.98	3.00	2.98	0.69
0.62	7.66	1.91	2.10	4.01	0.88	4.89	3.00	2.93	0.65
0.63	7.78	1.85	2.10	3.95	0.86	4.81	3.00	2.88	0.61
0.64	7.91	1.79	2.11	3.90	0.83	4.73	3.00	2.83	0.57
0.65	8.04	1.73	2.12	3.85	0.80	4.65	3.00	2.78	0.54
0.66	8.17	1.68	2.12	3.80	0.77	4.58	3.00	2.73	0.51
0.67	8.30	1.62	2.13	3.75	0.75	4.50	3.00	2.69	0.48
0.68	8.43	1.57	2.14	3.71	0.73	4.44	3.00	2.64	0.45
0.69	8.55	1.53	2.14	3.67	0.70	4.37	3.00	2.59	0.42
0.70	8.68	1.48	2.15	3.63	0.68	4.31	3.00	2.55	0.40
0.71	8.81	1.43	2.16	3.59	0.66	4.25	3.00	2.51	0.38
0.72	8.94	1.39	2.16	3.55	0.64	4.19	3.00	2.46	0.36
0.73	9.07	1.35	2.17	3.51	0.62	4.13	3.00	2.42	0.34
0.74	9.21	1.30	2.18	3.48	0.60	4.08	3.00	2.38	0.32
0.75	9.34	1.26	2.18	3.45	0.58	4.03	3.00	2.34	0.30
0.76	9.47	1.23	2.19	3.41	0.56	3.98	3.00	2.30	0.29
0.77	9.60	1.19	2.19	3.38	0.55	3.93	3.00	2.26	0.28

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

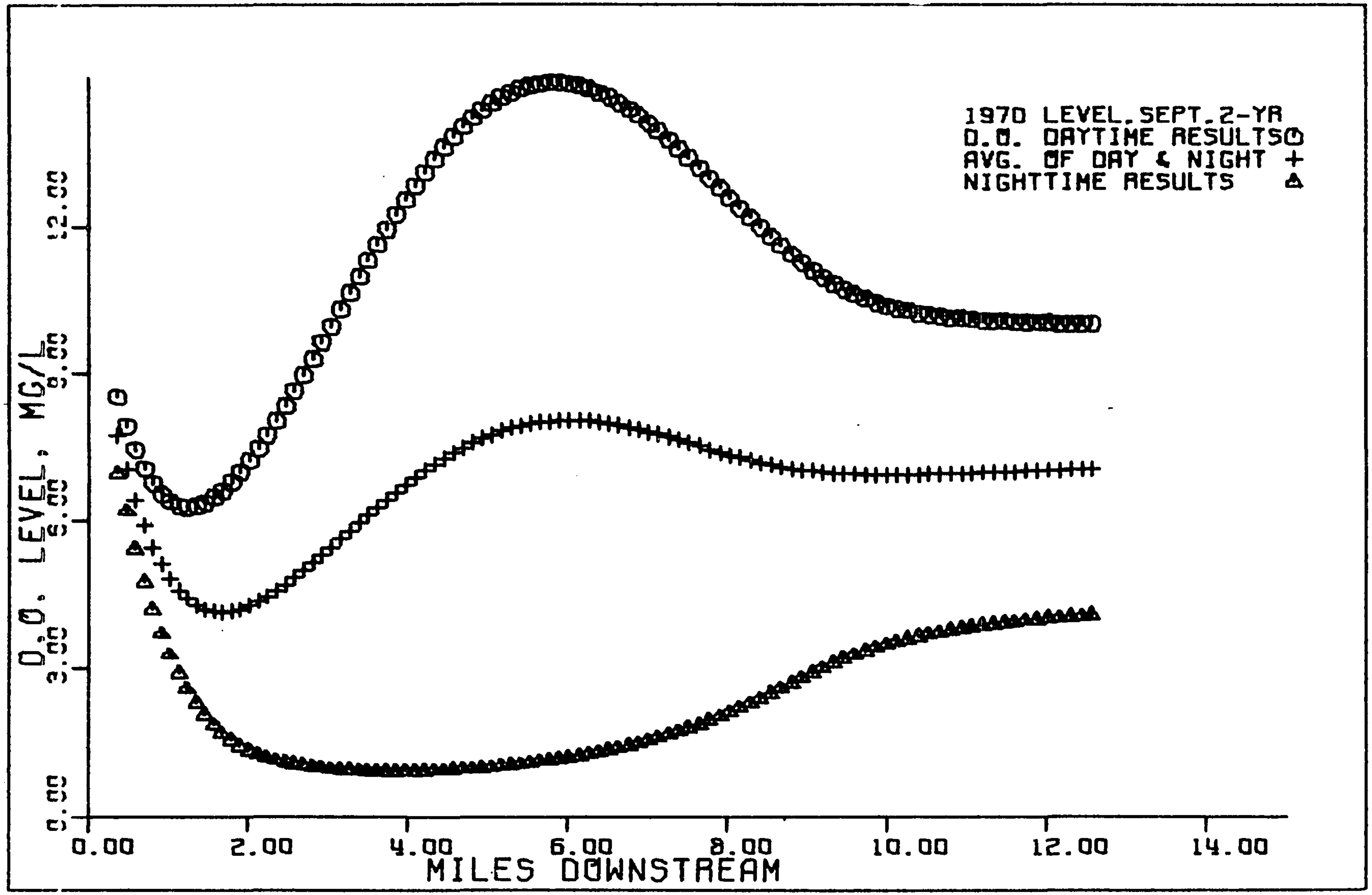
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	9.73	1.15	2.20	3.35	0.53	3.88	3.00	2.23	0.26
0.79	9.86	1.12	2.21	3.33	0.51	3.84	3.00	2.19	0.25
0.80	10.00	1.09	2.21	3.30	0.50	3.80	3.00	2.15	0.24
0.81	10.13	1.05	2.22	3.27	0.48	3.76	3.00	2.12	0.23
0.82	10.26	1.02	2.23	3.25	0.47	3.72	3.00	2.08	0.22
0.83	10.39	0.99	2.23	3.22	0.46	3.68	3.00	2.05	0.21
0.84	10.53	0.96	2.24	3.20	0.44	3.65	3.00	2.01	0.20
0.85	10.66	0.93	2.25	3.18	0.43	3.61	3.00	1.98	0.20
0.86	10.80	0.91	2.25	3.16	0.42	3.58	3.00	1.95	0.19
0.87	10.93	0.88	2.26	3.14	0.41	3.55	3.00	1.92	0.18
0.88	11.07	0.85	2.27	3.12	0.40	3.51	3.00	1.89	0.17
0.89	11.20	0.83	2.27	3.10	0.38	3.48	3.00	1.86	0.17
0.90	11.34	0.80	2.28	3.08	0.37	3.46	3.00	1.83	0.16
0.91	11.47	0.78	2.28	3.07	0.36	3.43	3.00	1.80	0.16
0.92	11.61	0.76	2.29	3.05	0.35	3.40	3.00	1.77	0.15
0.93	11.74	0.74	2.30	3.03	0.34	3.38	3.00	1.74	0.15
0.94	11.88	0.71	2.30	3.02	0.34	3.35	3.00	1.71	0.14
0.95	12.02	0.69	2.31	3.00	0.33	3.33	3.00	1.69	0.14
0.96	12.16	0.67	2.32	2.99	0.32	3.31	3.00	1.66	0.13
0.97	12.29	0.66	2.32	2.98	0.31	3.29	3.00	1.63	0.13
0.98	12.43	0.64	2.33	2.96	0.30	3.27	3.00	1.61	0.12
0.99	12.57	0.62	2.33	2.95	0.29	3.25	3.00	1.58	0.12

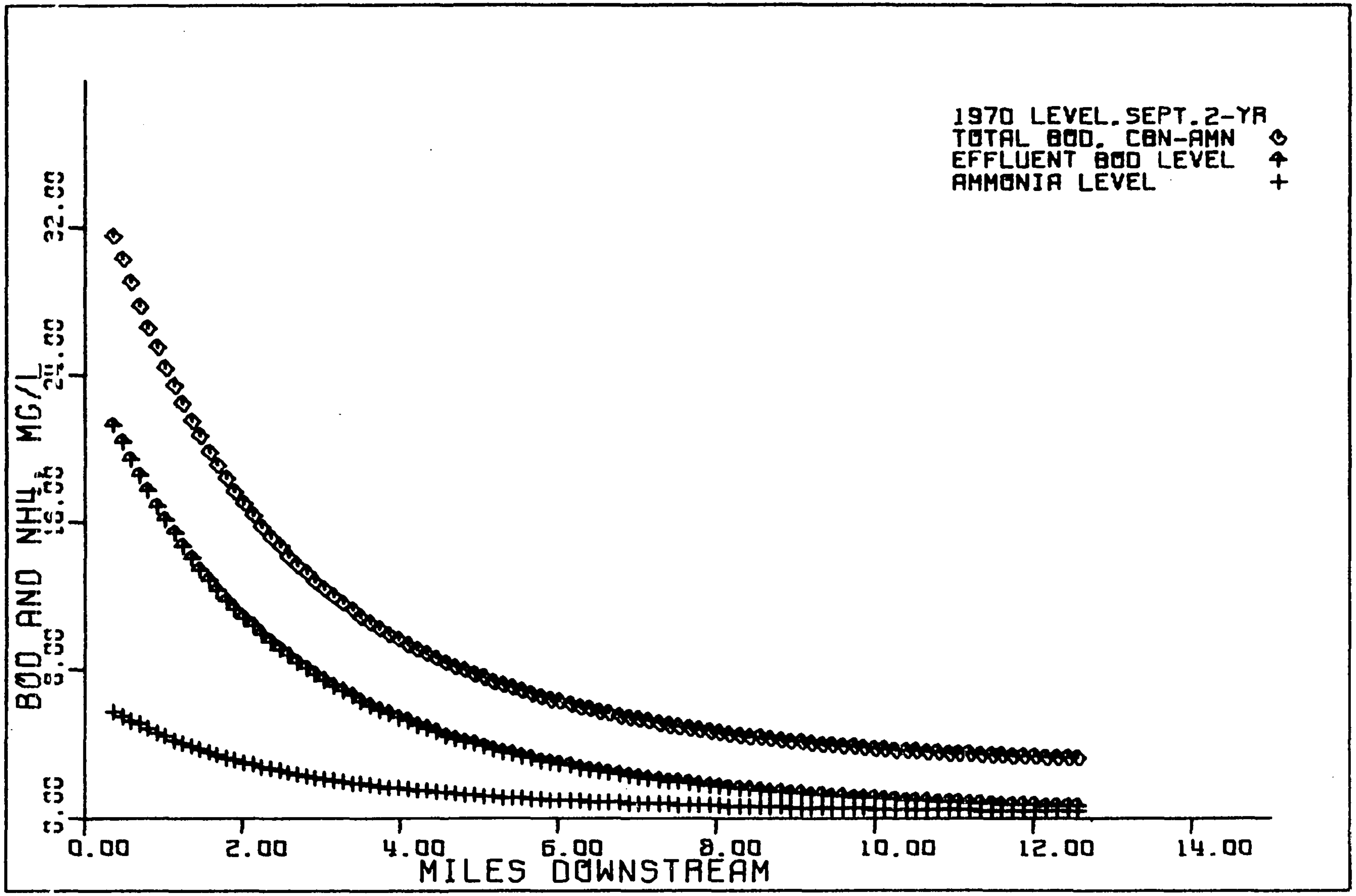
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.51	0.37	0.0	6.95	0.37	0.0
MINIMUM DO, MG/L	6.27	1.24	0.08	0.92	3.86	0.31
FINAL DO, MG/L	10.39	10.00	0.80	3.49	10.00	0.80
DO DEFICIT						
INITIAL, MG/L	-0.19	0.37	0.0	2.31	0.37	0.0
FINAL, MG/L	-2.46	10.00	0.80	5.90	10.00	0.80
RIVER DISCHARGE						
INITIAL, CFS	19.04	0.37	0.0	19.04	0.37	0.0
FINAL, CFS	33.48	10.00	0.80	33.48	10.00	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	72.56	0.37	0.0	63.11	0.37	0.0
FINAL, DEG F	76.96	10.00	0.80	62.01	10.00	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	21.25	0.37	0.0	21.25	0.37	0.0
FINAL BOD, MG/L	0.74	10.00	0.80	1.43	10.00	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.06	0.37	0.0	0.06	0.37	0.0
FINAL BOD IN RIVER	1.98	10.00	0.80	2.45	10.00	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	7.93	0.37	0.0	7.93	0.37	0.0
FINAL BOD, MG/L	0.14	10.00	0.80	0.85	10.00	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	30.91	0.37	0.0	32.05	0.37	0.0
FINAL VALUE, MG/L	2.86	10.00	0.80	4.74	10.00	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	5.80	0.37	0.0	5.80	0.37	0.0
FINAL VALUE, MG/L	0.40	10.00	0.80	0.62	10.00	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	5.59	0.37	0.0	5.59	0.37	0.0
FINAL VALUE, MG/L	3.00	10.00	0.80	3.00	10.00	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	9.50	0.37	0.0	9.50	0.37	0.0
FINAL VALUE, MG/L	1.56	10.00	0.80	2.75	10.00	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	37.05	0.37	0.0	37.05	0.37	0.0
FINAL PERCENT	0.10	10.00	0.80	0.38	10.00	0.80


1970 LEVEL.SEPT.2-YR
D.O. DAYTIME RESULTS O
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS Δ
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


1970 LEVEL.SEPT.2-YR
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

C. Computer Results for 1970 Status Study, October-November, 2 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
4.55	60.00	75.00	0.0	40.00	0.080	0.0	17.00	8.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
67.00	52.00	125.00	70.00	3.00	0.140	0.0	0.40	3.00	0.40	0.10	70.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
5.00	0.75	115.00	60.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
67.00	52.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	1.50	2.50	1.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.27
     RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
     SEASON : OCT-NOV

 GAMMA1 =    0.80  , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS     70.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   3.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    7.04 CFS, RIVER Q =    5.00 CFS, TOTAL Q =  12.04 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =    1.00 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	67.0	52.0		5.0	11.06	7.45		0.40
0.0	0.37	62.9	56.7	59.8	12.0	8.81	7.31	8.06	10.11
0.01	0.46	63.1	56.4	59.8	12.1	8.08	6.38	7.23	9.81
0.02	0.55	63.4	56.2	59.8	12.2	7.44	5.43	6.44	9.52
0.03	0.64	63.6	55.9	59.7	12.2	6.90	4.60	5.75	9.23
0.04	0.73	63.7	55.7	59.7	12.3	6.46	3.89	5.17	8.96
0.05	0.83	63.9	55.5	59.7	12.4	6.09	3.28	4.69	8.69
0.06	0.92	64.1	55.3	59.7	12.5	5.80	2.75	4.28	8.44
0.07	1.01	64.3	55.1	59.7	12.5	5.57	2.30	3.94	8.19
0.08	1.10	64.4	55.0	59.7	12.6	5.40	1.92	3.66	7.94
0.09	1.19	64.6	54.8	59.7	12.7	5.29	1.60	3.44	7.71
0.10	1.28	64.7	54.6	59.7	12.7	5.22	1.37	3.29	7.49
0.11	1.38	64.8	54.5	59.7	12.8	5.19	1.20	3.19	7.29
0.12	1.47	64.9	54.3	59.6	12.9	5.20	1.08	3.14	7.09
0.13	1.56	65.1	54.2	59.6	12.9	5.25	0.99	3.12	6.91
0.14	1.66	65.2	54.1	59.6	13.0	5.33	0.93	3.13	6.73
0.15	1.75	65.3	54.0	59.6	13.1	5.43	0.89	3.16	6.56
0.16	1.84	65.4	53.9	59.6	13.1	5.56	0.87	3.21	6.39
0.17	1.94	65.5	53.8	59.6	13.2	5.71	0.85	3.28	6.23
0.18	2.03	65.5	53.7	59.6	13.3	5.88	0.85	3.36	6.07
0.19	2.12	65.6	53.6	59.6	13.4	6.07	0.85	3.46	5.92
0.20	2.22	65.7	53.5	59.6	13.4	6.27	0.85	3.56	5.77
0.21	2.31	65.8	53.4	59.6	13.5	6.48	0.87	3.67	5.63
0.22	2.41	65.8	53.3	59.6	13.6	6.71	0.88	3.79	5.49
0.23	2.50	65.9	53.2	59.6	13.6	6.94	0.89	3.92	5.36
0.24	2.60	66.0	53.2	59.6	13.7	7.19	0.91	4.05	5.22
0.25	2.69	66.0	53.1	59.6	13.8	7.44	0.93	4.18	5.10

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.79	66.1	53.0	59.6	13.9	7.70	0.95	4.32	4.97
0.27	2.88	66.1	53.0	59.6	13.9	7.96	0.97	4.47	4.85
0.28	2.98	66.2	52.9	59.6	14.0	8.23	0.99	4.61	4.73
0.29	3.07	66.2	52.9	59.6	14.1	8.50	1.01	4.75	4.61
0.30	3.17	66.3	52.8	59.6	14.1	8.78	1.03	4.90	4.50
0.31	3.27	66.3	52.8	59.5	14.2	9.05	1.05	5.05	4.39
0.32	3.36	66.3	52.7	59.5	14.3	9.33	1.07	5.20	4.29
0.33	3.46	66.4	52.7	59.5	14.4	9.60	1.09	5.35	4.18
0.34	3.56	66.4	52.7	59.5	14.4	9.87	1.11	5.49	4.08
0.35	3.65	66.5	52.6	59.5	14.5	10.15	1.14	5.64	3.98
0.36	3.75	66.5	52.6	59.5	14.6	10.42	1.16	5.79	3.89
0.37	3.85	66.5	52.6	59.5	14.7	10.69	1.18	5.93	3.79
0.38	3.95	66.5	52.5	59.5	14.7	10.95	1.20	6.08	3.70
0.39	4.04	66.6	52.5	59.5	14.8	11.21	1.23	6.22	3.61
0.40	4.14	66.6	52.5	59.5	14.9	11.47	1.25	6.36	3.52
0.41	4.24	66.6	52.4	59.5	14.9	11.72	1.27	6.49	3.44
0.42	4.34	66.6	52.4	59.5	15.0	11.96	1.29	6.63	3.36
0.43	4.44	66.7	52.4	59.5	15.1	12.20	1.32	6.76	3.28
0.44	4.53	66.7	52.4	59.5	15.2	12.44	1.34	6.89	3.20
0.45	4.63	66.7	52.4	59.5	15.2	12.66	1.36	7.01	3.12
0.46	4.73	66.7	52.3	59.5	15.3	12.88	1.39	7.13	3.05
0.47	4.83	66.7	52.3	59.5	15.4	13.10	1.41	7.25	2.97
0.48	4.93	66.7	52.3	59.5	15.5	13.30	1.43	7.37	2.90
0.49	5.03	66.8	52.3	59.5	15.5	13.50	1.46	7.48	2.83
0.50	5.13	66.8	52.3	59.5	15.6	13.68	1.48	7.58	2.76
0.51	5.23	66.8	52.2	59.5	15.7	13.86	1.50	7.68	2.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	5.33	66.8	52.2	59.5	15.8	14.03	1.53	7.78	2.63
0.53	5.43	66.8	52.2	59.5	15.8	14.19	1.55	7.87	2.57
0.54	5.53	66.8	52.2	59.5	15.9	14.34	1.57	7.96	2.51
0.55	5.63	66.8	52.2	59.5	16.0	14.48	1.60	8.04	2.45
0.56	5.73	66.8	52.2	59.5	16.1	14.61	1.62	8.12	2.39
0.57	5.83	66.8	52.2	59.5	16.1	14.73	1.65	8.19	2.33
0.58	5.93	66.9	52.2	59.5	16.2	14.84	1.67	8.26	2.28
0.59	6.04	66.9	52.2	59.5	16.3	14.94	1.70	8.32	2.22
0.60	6.14	66.9	52.1	59.5	16.4	15.03	1.72	8.38	2.17
0.61	6.24	66.9	52.1	59.5	16.4	15.10	1.75	8.43	2.12
0.62	6.34	66.9	52.1	59.5	16.5	15.17	1.77	8.47	2.07
0.63	6.44	66.9	52.1	59.5	16.6	15.23	1.80	8.51	2.02
0.64	6.54	66.9	52.1	59.5	16.7	15.28	1.83	8.55	1.97
0.65	6.65	66.9	52.1	59.5	16.8	15.31	1.85	8.58	1.92
0.66	6.75	66.9	52.1	59.5	16.8	15.34	1.88	8.61	1.87
0.67	6.85	66.9	52.1	59.5	16.9	15.35	1.91	8.63	1.83
0.68	6.95	66.9	52.1	59.5	17.0	15.36	1.93	8.65	1.78
0.69	7.06	66.9	52.1	59.5	17.1	15.35	1.96	8.66	1.74
0.70	7.16	66.9	52.1	59.5	17.1	15.34	1.99	8.66	1.70
0.71	7.26	66.9	52.1	59.5	17.2	15.31	2.02	8.67	1.66
0.72	7.37	66.9	52.1	59.5	17.3	15.28	2.05	8.66	1.62
0.73	7.47	66.9	52.1	59.5	17.4	15.24	2.08	8.66	1.58
0.74	7.58	66.9	52.1	59.5	17.4	15.19	2.11	8.65	1.54
0.75	7.68	66.9	52.1	59.5	17.5	15.13	2.15	8.64	1.50
0.76	7.78	66.9	52.1	59.5	17.6	15.06	2.18	8.62	1.47
0.77	7.89	67.0	52.1	59.5	17.7	14.98	2.22	8.60	1.43

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	7.99	67.0	52.1	59.5	17.8	14.90	2.25	8.58	1.40
0.79	8.10	67.0	52.0	59.5	17.8	14.81	2.29	8.55	1.36
0.80	8.20	67.0	52.0	59.5	17.9	14.71	2.33	8.52	1.33
0.81	8.31	67.0	52.0	59.5	18.0	14.61	2.37	8.49	1.30
0.82	8.41	67.0	52.0	59.5	18.1	14.50	2.41	8.46	1.27
0.83	8.52	67.0	52.0	59.5	18.2	14.39	2.45	8.42	1.24
0.84	8.62	67.0	52.0	59.5	18.2	14.27	2.49	8.38	1.21
0.85	8.73	67.0	52.0	59.5	18.3	14.15	2.54	8.34	1.18
0.86	8.84	67.0	52.0	59.5	18.4	14.02	2.58	8.30	1.15
0.87	8.94	67.0	52.0	59.5	18.5	13.89	2.63	8.26	1.13
0.88	9.05	67.0	52.0	59.5	18.6	13.76	2.67	8.22	1.10
0.89	9.16	67.0	52.0	59.5	18.6	13.62	2.72	8.17	1.08
0.90	9.26	67.0	52.0	59.5	18.7	13.49	2.77	8.13	1.05
0.91	9.37	67.0	52.0	59.5	18.8	13.35	2.82	8.08	1.03
0.92	9.48	67.0	52.0	59.5	18.9	13.21	2.87	8.04	1.02
0.93	9.58	67.0	52.0	59.5	19.0	13.07	2.92	8.00	1.00
0.94	9.69	67.0	52.0	59.5	19.0	12.93	2.98	7.96	0.98
0.95	9.80	67.0	52.0	59.5	19.1	12.80	3.03	7.92	0.97
0.96	9.91	67.0	52.0	59.5	19.2	12.66	3.09	7.88	0.95
0.97	10.01	67.0	52.0	59.5	19.3	12.53	3.15	7.84	0.94
0.98	10.12	67.0	52.0	59.5	19.4	12.40	3.20	7.80	0.92
0.99	10.23	67.0	52.0	59.5	19.4	12.27	3.26	7.77	0.91

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	3.00	2.43	5.43	0.55	5.98	3.00	0.40	0.10
0.0	0.37	32.36	3.16	35.52	13.83	49.35	5.92	17.71	58.52
0.01	0.46	31.29	3.16	34.46	13.42	47.87	5.89	17.47	55.51
0.02	0.55	30.04	3.14	33.18	13.02	46.20	5.85	17.23	52.65
0.03	0.64	28.85	3.12	31.97	12.63	44.60	5.80	17.00	49.94
0.04	0.73	27.72	3.10	30.82	12.26	43.07	5.76	16.77	47.37
0.05	0.83	26.63	3.08	29.72	11.89	41.61	5.71	16.54	44.93
0.06	0.92	25.60	3.07	28.67	11.54	40.21	5.66	16.32	42.63
0.07	1.01	24.61	3.05	27.67	11.20	38.86	5.61	16.10	40.44
0.08	1.10	23.67	3.04	26.71	10.87	37.58	5.56	15.88	38.37
0.09	1.19	22.78	3.03	25.80	10.55	36.35	5.50	15.67	36.40
0.10	1.28	21.92	3.02	24.93	10.25	35.19	5.44	15.45	34.54
0.11	1.38	21.10	3.01	24.11	9.97	34.08	5.36	15.25	32.77
0.12	1.47	20.31	3.00	23.31	9.70	33.02	5.28	15.04	31.10
0.13	1.56	19.57	2.99	22.56	9.45	32.01	5.20	14.84	29.51
0.14	1.66	18.85	2.99	21.83	9.20	31.04	5.11	14.64	28.01
0.15	1.75	18.16	2.98	21.14	8.97	30.11	5.03	14.44	26.58
0.16	1.84	17.51	2.98	20.48	8.74	29.22	4.95	14.25	25.23
0.17	1.94	16.88	2.97	19.85	8.52	28.37	4.86	14.06	23.95
0.18	2.03	16.28	2.97	19.25	8.31	27.55	4.78	13.87	22.74
0.19	2.12	15.70	2.97	18.67	8.10	26.77	4.70	13.69	21.59
0.20	2.22	15.15	2.97	18.11	7.90	26.01	4.62	13.51	20.50
0.21	2.31	14.62	2.97	17.58	7.70	25.29	4.54	13.33	19.46
0.22	2.41	14.11	2.97	17.08	7.51	24.59	4.46	13.15	18.48
0.23	2.50	13.62	2.97	16.59	7.33	23.92	4.38	12.98	17.55
0.24	2.60	13.16	2.97	16.12	7.15	23.27	4.30	12.81	16.67
0.25	2.69	12.71	2.97	15.68	6.97	22.65	4.23	12.64	15.84

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.79	12.28	2.97	15.25	6.80	22.05	4.15	12.47	15.05
0.27	2.88	11.86	2.97	14.84	6.63	21.47	4.08	12.31	14.29
0.28	2.98	11.47	2.98	14.45	6.47	20.92	4.01	12.14	13.58
0.29	3.07	11.09	2.98	14.07	6.31	20.38	3.94	11.98	12.91
0.30	3.17	10.72	2.99	13.71	6.16	19.86	3.87	11.83	12.27
0.31	3.27	10.37	2.99	13.36	6.01	19.37	3.80	11.67	11.66
0.32	3.36	10.03	2.99	13.02	5.86	18.89	3.74	11.52	11.08
0.33	3.46	9.70	3.00	12.70	5.72	18.43	3.67	11.37	10.53
0.34	3.56	9.39	3.01	12.40	5.58	17.98	3.61	11.22	10.01
0.35	3.65	9.09	3.01	12.10	5.45	17.55	3.55	11.08	9.52
0.36	3.75	8.80	3.02	11.82	5.32	17.13	3.48	10.93	9.05
0.37	3.85	8.52	3.03	11.55	5.19	16.73	3.42	10.79	8.61
0.38	3.95	8.25	3.03	11.28	5.06	16.35	3.37	10.65	8.19
0.39	4.04	7.99	3.04	11.03	4.94	15.97	3.31	10.51	7.79
0.40	4.14	7.74	3.05	10.79	4.82	15.61	3.25	10.38	7.41
0.41	4.24	7.50	3.06	10.56	4.71	15.26	3.20	10.24	7.05
0.42	4.34	7.27	3.06	10.33	4.59	14.93	3.14	10.11	6.71
0.43	4.44	7.05	3.07	10.12	4.48	14.60	3.09	9.98	6.38
0.44	4.53	6.83	3.08	9.91	4.37	14.29	3.07	9.86	6.07
0.45	4.63	6.62	3.09	9.71	4.27	13.98	3.05	9.73	5.78
0.46	4.73	6.42	3.10	9.52	4.17	13.69	3.03	9.61	5.50
0.47	4.83	6.23	3.11	9.34	4.07	13.40	3.01	9.48	5.24
0.48	4.93	6.04	3.12	9.16	3.97	13.13	3.00	9.36	4.99
0.49	5.03	5.86	3.13	8.99	3.87	12.86	3.00	9.24	4.75
0.50	5.13	5.69	3.14	8.83	3.78	12.61	3.00	9.13	4.52
0.51	5.23	5.52	3.15	8.67	3.69	12.36	3.00	9.01	4.31

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	5.33	5.36	3.16	8.52	3.60	12.12	3.00	8.90	4.10
0.53	5.43	5.20	3.17	8.37	3.52	11.89	3.00	8.79	3.91
0.54	5.53	5.05	3.18	8.23	3.43	11.66	3.00	8.67	3.72
0.55	5.63	4.90	3.19	8.09	3.35	11.44	3.00	8.57	3.55
0.56	5.73	4.76	3.20	7.96	3.27	11.23	3.00	8.46	3.38
0.57	5.83	4.63	3.21	7.83	3.19	11.03	3.00	8.35	3.22
0.58	5.93	4.49	3.22	7.71	3.11	10.83	3.00	8.25	3.07
0.59	6.04	4.37	3.23	7.60	3.04	10.64	3.00	8.14	2.92
0.60	6.14	4.24	3.24	7.48	2.97	10.45	3.00	8.04	2.79
0.61	6.24	4.12	3.25	7.37	2.90	10.27	3.00	7.94	2.66
0.62	6.34	4.01	3.26	7.27	2.83	10.09	3.00	7.84	2.53
0.63	6.44	3.89	3.27	7.17	2.76	9.92	3.00	7.75	2.42
0.64	6.54	3.79	3.28	7.07	2.69	9.76	3.00	7.65	2.30
0.65	6.65	3.68	3.30	6.98	2.63	9.60	3.00	7.56	2.20
0.66	6.75	3.58	3.31	6.89	2.56	9.45	3.00	7.46	2.09
0.67	6.85	3.48	3.32	6.80	2.50	9.30	3.00	7.37	2.00
0.68	6.95	3.38	3.33	6.71	2.44	9.15	3.00	7.28	1.91
0.69	7.06	3.29	3.34	6.63	2.38	9.01	3.00	7.19	1.82
0.70	7.16	3.20	3.35	6.55	2.32	8.88	3.00	7.10	1.74
0.71	7.26	3.11	3.36	6.48	2.27	8.74	3.00	7.02	1.66
0.72	7.37	3.03	3.38	6.41	2.21	8.62	3.00	6.93	1.58
0.73	7.47	2.95	3.39	6.34	2.16	8.49	3.00	6.85	1.51
0.74	7.58	2.87	3.40	6.27	2.10	8.37	3.00	6.76	1.44
0.75	7.68	2.79	3.41	6.20	2.05	8.26	3.00	6.68	1.37
0.76	7.78	2.72	3.42	6.14	2.00	8.14	3.00	6.60	1.31
0.77	7.89	2.65	3.43	6.08	1.96	8.04	3.00	6.52	1.25

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

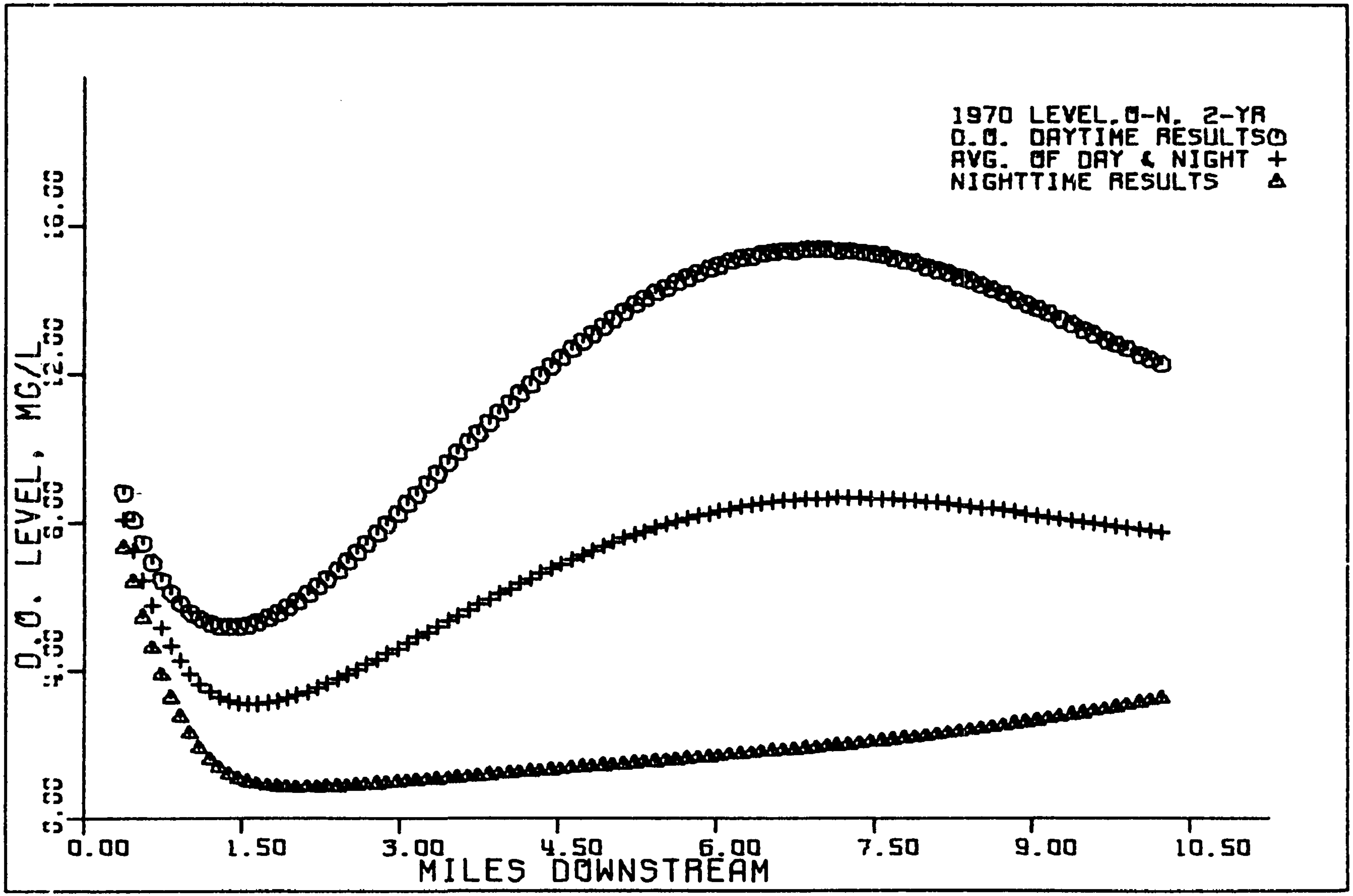
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	7.99	2.57	3.45	6.02	1.91	7.93	3.00	6.44	1.20
0.79	8.10	2.51	3.46	5.96	1.86	7.83	3.00	6.37	1.14
0.80	8.20	2.44	3.47	5.91	1.82	7.73	3.00	6.29	1.09
0.81	8.31	2.38	3.48	5.86	1.78	7.63	3.00	6.21	1.04
0.82	8.41	2.31	3.49	5.81	1.73	7.54	3.00	6.14	0.99
0.83	8.52	2.25	3.50	5.76	1.69	7.45	3.00	6.07	0.95
0.84	8.62	2.20	3.52	5.71	1.65	7.37	3.00	5.99	0.91
0.85	8.73	2.14	3.53	5.67	1.62	7.28	3.00	5.92	0.87
0.86	8.84	2.08	3.54	5.62	1.58	7.20	3.00	5.85	0.83
0.87	8.94	2.03	3.55	5.58	1.54	7.12	3.00	5.78	0.79
0.88	9.05	1.98	3.56	5.54	1.51	7.04	3.00	5.71	0.76
0.89	9.16	1.93	3.57	5.50	1.47	6.97	3.00	5.64	0.72
0.90	9.26	1.88	3.59	5.46	1.44	6.90	3.00	5.58	0.69
0.91	9.37	1.83	3.60	5.43	1.40	6.83	3.00	5.51	0.66
0.92	9.48	1.78	3.61	5.39	1.37	6.76	3.00	5.45	0.63
0.93	9.58	1.74	3.62	5.36	1.34	6.70	3.00	5.38	0.60
0.94	9.69	1.69	3.63	5.32	1.31	6.63	3.00	5.32	0.58
0.95	9.80	1.65	3.64	5.29	1.28	6.57	3.00	5.26	0.55
0.96	9.91	1.61	3.65	5.26	1.25	6.51	3.00	5.20	0.53
0.97	10.01	1.57	3.66	5.23	1.22	6.46	3.00	5.14	0.51
0.98	10.12	1.53	3.68	5.20	1.20	6.40	3.00	5.08	0.48
0.99	10.23	1.49	3.69	5.18	1.17	6.35	3.00	5.02	0.46

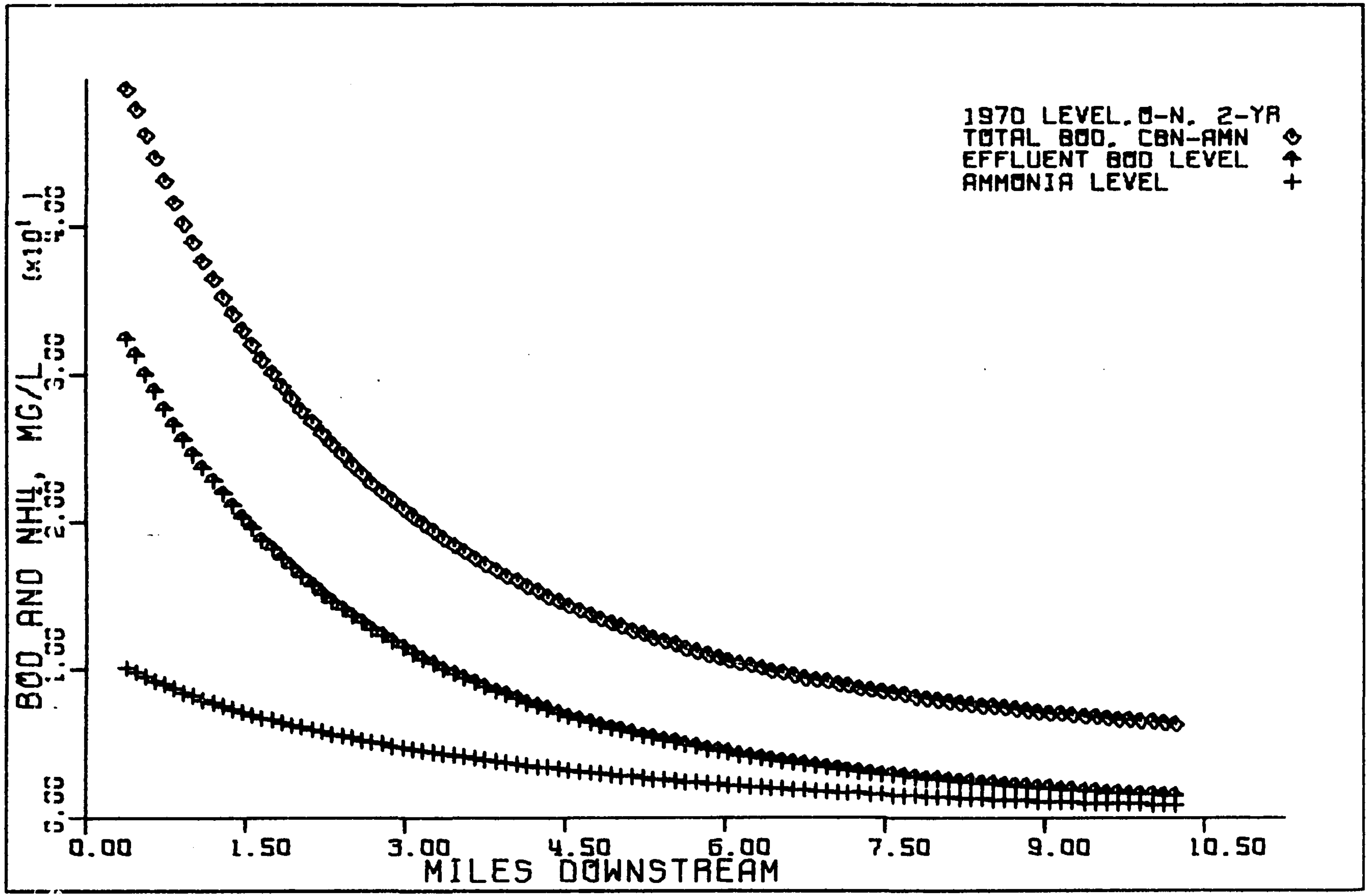
WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.81	0.37	0.0	7.31	0.37	0.0
MINIMUM DO, MG/L	5.19	1.38	0.11	0.85	2.03	0.18
FINAL DO, MG/L	14.71	8.20	0.80	2.33	8.20	0.80
DO DEFICIT						
INITIAL, MG/L	0.47	0.37	0.0	2.71	0.37	0.0
FINAL, MG/L	-5.86	8.20	0.80	8.31	8.20	0.80
RIVER DISCHARGE						
INITIAL, CFS	12.04	0.37	0.0	12.04	0.37	0.0
FINAL, CFS	17.92	8.20	0.80	17.92	8.20	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	62.91	0.37	0.0	56.68	0.37	0.0
FINAL, DEG F	66.96	8.20	0.80	52.05	8.20	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	32.36	0.37	0.0	32.36	0.37	0.0
FINAL BOD, MG/L	1.76	8.20	0.80	3.12	8.20	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.10	0.37	0.0	0.10	0.37	0.0
FINAL BOD IN RIVER	3.09	8.20	0.80	3.84	8.20	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	13.83	0.37	0.0	13.83	0.37	0.0
FINAL BOD, MG/L	0.76	8.20	0.80	2.88	8.20	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	48.62	0.37	0.0	50.08	0.37	0.0
FINAL VALUE, MG/L	5.62	8.20	0.80	9.84	8.20	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	10.11	0.37	0.0	10.11	0.37	0.0
FINAL VALUE, MG/L	0.56	8.20	0.80	2.10	8.20	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	5.92	0.37	0.0	5.92	0.37	0.0
FINAL VALUE, MG/L	3.00	8.20	0.80	3.00	8.20	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	17.71	0.37	0.0	17.71	0.37	0.0
FINAL VALUE, MG/L	5.16	8.20	0.80	7.42	8.20	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	58.52	0.37	0.0	58.52	0.37	0.0
FINAL PERCENT	0.45	8.20	0.80	1.73	8.20	0.80


1970 LEVEL.D-N. 2-YR
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
MILES DOWNSTREAM
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50


1970 LEVEL.0-N. 2-YR
TOTAL BOD. CBN-AMN ◇
EFFLUENT BOD LEVEL
AMMONIA LEVEL +
BOD AND NH4, MG/L (x10^1)
MILES DOWNSTREAM
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50

D. Computer Results for 1970 Status Study, Winter, 2 Yr,

Low Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.72	50.00	75.00	0.0	55.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	95.00	75.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
4.00	0.60	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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            AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
     SEASON : WINTER

 GAMMA1 =   0.80 , GAMMA2 =   0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    5.76 CFS, RIVER Q =    4.00 CFS, TOTAL Q =    9.76 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		4.0	13.50	10.66		0.40
0.0	0.37	42.6	42.6	42.6	9.8	10.37	9.21	9.79	14.92
0.02	0.54	41.5	41.5	41.5	9.9	8.99	8.24	8.61	14.42
0.04	0.71	40.4	40.4	40.4	10.0	7.96	7.31	7.63	13.97
0.06	0.87	39.5	39.5	39.5	10.1	7.22	6.65	6.94	13.54
0.08	1.04	38.7	38.7	38.7	10.2	6.71	6.21	6.46	13.13
0.10	1.21	38.0	38.0	38.0	10.3	6.38	5.94	6.16	12.75
0.12	1.38	37.3	37.3	37.3	10.4	6.18	5.79	5.98	12.38
0.14	1.56	36.7	36.7	36.7	10.5	6.08	5.74	5.91	12.04
0.16	1.73	36.2	36.2	36.2	10.6	6.06	5.76	5.91	11.71
0.18	1.90	35.8	35.8	35.8	10.7	6.10	5.83	5.97	11.39
0.20	2.07	35.4	35.4	35.4	10.8	6.19	5.95	6.07	11.09
0.22	2.25	35.0	35.0	35.0	10.9	6.31	6.09	6.20	10.80
0.24	2.42	34.7	34.7	34.7	11.0	6.45	6.26	6.36	10.52
0.26	2.60	34.4	34.4	34.4	11.1	6.62	6.44	6.53	10.25
0.28	2.77	34.1	34.1	34.1	11.2	6.79	6.63	6.71	9.99
0.30	2.95	33.9	33.9	33.9	11.3	6.97	6.83	6.90	9.74
0.32	3.13	33.7	33.7	33.7	11.4	7.16	7.03	7.10	9.50
0.34	3.30	33.5	33.5	33.5	11.5	7.35	7.23	7.29	9.27
0.36	3.48	33.3	33.3	33.3	11.6	7.54	7.43	7.48	9.04
0.38	3.66	33.2	33.2	33.2	11.7	7.72	7.62	7.67	8.82
0.40	3.84	33.1	33.1	33.1	11.8	7.90	7.81	7.86	8.61
0.42	4.02	32.9	32.9	32.9	11.9	8.08	8.00	8.04	8.40
0.44	4.20	32.8	32.8	32.8	12.1	8.26	8.18	8.22	8.20
0.46	4.38	32.8	32.8	32.8	12.2	8.42	8.35	8.39	8.01
0.48	4.57	32.7	32.7	32.7	12.3	8.59	8.52	8.55	7.82
0.50	4.75	32.6	32.6	32.6	12.4	8.74	8.68	8.71	7.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.93	32.5	32.5	32.5	12.5	8.89	8.84	8.87	7.46
0.54	5.12	32.5	32.5	32.5	12.6	9.04	8.99	9.01	7.28
0.56	5.30	32.4	32.4	32.4	12.7	8.54	8.48	8.51	7.11
0.58	5.48	32.4	32.4	32.4	12.8	8.06	8.00	8.03	6.95
0.60	5.67	32.3	32.3	32.3	12.9	7.60	7.54	7.57	6.79
0.62	5.86	32.3	32.3	32.3	13.1	7.16	7.10	7.13	6.63
0.64	6.04	32.3	32.3	32.3	13.2	6.74	6.68	6.71	6.48
0.66	6.23	32.2	32.2	32.2	13.3	6.35	6.28	6.31	6.33
0.68	6.42	32.2	32.2	32.2	13.4	5.97	5.90	5.93	6.19
0.70	6.61	32.2	32.2	32.2	13.5	5.60	5.53	5.57	6.05
0.72	6.80	32.2	32.2	32.2	13.6	5.26	5.18	5.22	5.91
0.74	6.99	32.2	32.2	32.2	13.7	4.93	4.85	4.89	5.78
0.76	7.18	32.1	32.1	32.1	13.8	4.61	4.54	4.58	5.65
0.78	7.37	32.1	32.1	32.1	14.0	4.31	4.24	4.27	5.52
0.80	7.56	32.1	32.1	32.1	14.1	4.03	3.95	3.99	5.40
0.82	7.75	32.1	32.1	32.1	14.2	3.75	3.68	3.71	5.28
0.84	7.94	32.1	32.1	32.1	14.3	3.49	3.41	3.45	5.16
0.86	8.14	32.1	32.1	32.1	14.4	3.25	3.17	3.21	5.05
0.88	8.33	32.1	32.1	32.1	14.5	3.01	2.93	2.97	4.94
0.90	8.53	32.1	32.1	32.1	14.7	2.79	2.71	2.75	4.83
0.92	8.72	32.1	32.1	32.1	14.8	2.57	2.49	2.53	4.72
0.94	8.92	32.0	32.0	32.0	14.9	2.37	2.29	2.33	4.62
0.96	9.11	32.0	32.0	32.0	15.0	2.18	2.09	2.14	4.52
0.98	9.31	32.0	32.0	32.0	15.1	1.99	1.91	1.95	4.42
1.00	9.51	32.0	32.0	32.0	15.2	1.82	1.74	1.78	4.32
1.02	9.70	32.0	32.0	32.0	15.4	1.66	1.59	1.62	4.23

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	9.90	32.0	32.0	32.0	15.5	1.52	1.45	1.48	4.15
1.06	10.10	32.0	32.0	32.0	15.6	1.39	1.32	1.36	4.07
1.08	10.30	32.0	32.0	32.0	15.7	1.28	1.21	1.24	4.00
1.10	10.50	32.0	32.0	32.0	15.8	1.17	1.11	1.14	3.92
1.12	10.70	32.0	32.0	32.0	16.0	1.08	1.02	1.05	3.86
1.14	10.90	32.0	32.0	32.0	16.1	0.99	0.94	0.96	3.79
1.16	11.11	32.0	32.0	32.0	16.2	0.92	0.36	0.89	3.73
1.18	11.31	32.0	32.0	32.0	16.3	0.85	0.79	0.82	3.67
1.20	11.51	32.0	32.0	32.0	16.4	0.79	0.73	0.76	3.61
1.22	11.71	32.0	32.0	32.0	16.6	0.73	0.68	0.70	3.56
1.24	11.92	32.0	32.0	32.0	16.7	0.68	0.63	0.66	3.51
1.26	12.12	32.0	32.0	32.0	16.8	0.63	0.59	0.61	3.45
1.28	12.33	32.0	32.0	32.0	16.9	0.59	0.55	0.57	3.41
1.30	12.53	32.0	32.0	32.0	17.1	0.56	0.51	0.54	3.36
1.32	12.74	32.0	32.0	32.0	17.2	0.53	0.48	0.50	3.31
1.34	12.95	32.0	32.0	32.0	17.3	0.50	0.45	0.48	3.27
1.36	13.16	32.0	32.0	32.0	17.4	0.47	0.43	0.45	3.22
1.38	13.36	32.0	32.0	32.0	17.6	0.45	0.41	0.43	3.18
1.40	13.57	32.0	32.0	32.0	17.7	0.43	0.39	0.41	3.13
1.42	13.78	32.0	32.0	32.0	17.8	0.41	0.37	0.39	3.09
1.44	13.99	32.0	32.0	32.0	17.9	0.39	0.35	0.37	3.05
1.46	14.20	32.0	32.0	32.0	18.1	0.38	0.34	0.36	3.01
1.48	14.41	32.0	32.0	32.0	18.2	0.37	0.33	0.35	2.97
1.50	14.62	32.0	32.0	32.0	18.3	0.35	0.32	0.34	2.93
1.52	14.84	32.0	32.0	32.0	18.4	0.35	0.31	0.33	2.89
1.54	15.05	32.0	32.0	32.0	18.6	0.34	0.30	0.32	2.85

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	15.26	32.0	32.0	32.0	18.7	0.33	0.29	0.31	2.81
1.58	15.48	32.0	32.0	32.0	18.8	0.32	0.29	0.31	2.78
1.60	15.69	32.0	32.0	32.0	19.0	0.32	0.28	0.30	2.74
1.62	15.90	32.0	32.0	32.0	19.1	0.32	0.28	0.30	2.70
1.64	16.12	32.0	32.0	32.0	19.2	0.31	0.28	0.29	2.67
1.66	16.34	32.0	32.0	32.0	19.3	0.31	0.28	0.29	2.63
1.68	16.55	32.0	32.0	32.0	19.5	0.31	0.27	0.29	2.60
1.70	16.77	32.0	32.0	32.0	19.6	0.31	0.27	0.29	2.57
1.72	16.99	32.0	32.0	32.0	19.7	0.31	0.27	0.29	2.53
1.74	17.20	32.0	32.0	32.0	19.9	0.31	0.27	0.29	2.50
1.76	17.42	32.0	32.0	32.0	20.0	0.31	0.27	0.29	2.47
1.78	17.64	32.0	32.0	32.0	20.1	0.31	0.27	0.29	2.44
1.80	17.86	32.0	32.0	32.0	20.3	0.31	0.27	0.29	2.41
1.82	18.08	32.0	32.0	32.0	20.4	0.31	0.28	0.29	2.37
1.84	18.30	32.0	32.0	32.0	20.5	0.31	0.28	0.29	2.34
1.86	18.52	32.0	32.0	32.0	20.7	0.31	0.28	0.29	2.31
1.88	18.74	32.0	32.0	32.0	20.8	0.31	0.28	0.29	2.29
1.90	18.97	32.0	32.0	32.0	20.9	0.31	0.28	0.30	2.26
1.92	19.19	32.0	32.0	32.0	21.1	0.31	0.28	0.30	2.23
1.94	19.41	32.0	32.0	32.0	21.2	0.31	0.28	0.30	2.20
1.96	19.64	32.0	32.0	32.0	21.3	0.31	0.28	0.30	2.17
1.98	19.86	32.0	32.0	32.0	21.5	0.31	0.28	0.30	2.15

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	1.52	3.52	0.55	4.06	3.00	0.40	0.10
0.0	0.37	43.99	1.91	45.89	20.41	66.30	4.18	17.87	59.05
0.02	0.54	41.89	1.94	43.83	19.73	63.57	4.24	17.55	55.07
0.04	0.71	39.56	1.96	41.52	19.10	60.62	4.30	17.25	51.46
0.06	0.87	37.42	1.98	39.40	18.52	57.92	4.34	16.96	48.17
0.08	1.04	35.46	2.00	37.46	17.96	55.42	4.38	16.68	45.15
0.10	1.21	33.65	2.02	35.67	17.44	53.11	4.40	16.41	42.38
0.12	1.38	31.97	2.05	34.01	16.94	50.95	4.43	16.15	39.82
0.14	1.56	30.40	2.07	32.48	16.47	48.94	4.45	15.89	37.46
0.16	1.73	28.95	2.09	31.04	16.02	47.06	4.46	15.65	35.27
0.18	1.90	27.59	2.12	29.71	15.59	45.29	4.47	15.41	33.23
0.20	2.07	26.31	2.15	28.46	15.17	43.63	4.48	15.17	31.33
0.22	2.25	25.12	2.17	27.29	14.77	42.06	4.48	14.95	29.56
0.24	2.42	23.99	2.20	26.19	14.39	40.58	4.48	14.72	27.90
0.26	2.60	22.93	2.22	25.16	14.03	39.18	4.48	14.51	26.35
0.28	2.77	21.93	2.25	24.18	13.67	37.85	4.48	14.30	24.89
0.30	2.95	20.99	2.27	23.26	13.33	36.59	4.47	14.09	23.53
0.32	3.13	20.10	2.30	22.40	13.00	35.39	4.47	13.89	22.25
0.34	3.30	19.25	2.32	21.58	12.68	34.25	4.46	13.69	21.04
0.36	3.48	18.45	2.35	20.80	12.37	33.17	4.45	13.50	19.91
0.38	3.66	17.69	2.37	20.06	12.07	32.13	4.43	13.31	18.84
0.40	3.84	16.97	2.40	19.37	11.78	31.14	4.42	13.12	17.83
0.42	4.02	16.28	2.42	18.70	11.49	30.20	4.41	12.94	16.89
0.44	4.20	15.63	2.45	18.07	11.22	29.29	4.39	12.76	15.99
0.46	4.38	15.01	2.47	17.48	10.95	28.43	4.37	12.59	15.15
0.48	4.57	14.42	2.49	16.91	10.70	27.60	4.36	12.41	14.35
0.50	4.75	13.85	2.51	16.37	10.44	26.81	4.34	12.24	13.59

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.93	13.31	2.54	15.85	10.20	26.05	4.32	12.08	12.88
0.54	5.12	12.80	2.56	15.36	9.96	25.32	4.30	11.92	12.21
0.56	5.30	12.31	2.58	14.89	9.73	24.62	4.28	11.76	11.57
0.58	5.48	11.84	2.60	14.45	9.51	23.95	4.25	11.60	10.97
0.60	5.67	11.40	2.62	14.02	9.29	23.31	4.23	11.45	10.40
0.62	5.86	10.97	2.65	13.62	9.07	22.69	4.21	11.29	9.86
0.64	6.04	10.56	2.67	13.23	8.87	22.09	4.18	11.15	9.35
0.66	6.23	10.17	2.69	12.86	8.66	21.52	4.16	11.00	8.87
0.68	6.42	9.80	2.71	12.50	8.47	20.97	4.14	10.86	8.41
0.70	6.61	9.44	2.73	12.17	8.28	20.44	4.11	10.71	7.98
0.72	6.80	9.10	2.75	11.84	8.09	19.93	4.09	10.58	7.57
0.74	6.99	8.77	2.77	11.53	7.91	19.44	4.06	10.44	7.18
0.76	7.18	8.45	2.79	11.24	7.73	18.97	4.03	10.30	6.81
0.78	7.37	8.15	2.80	10.95	7.56	18.51	4.01	10.17	6.46
0.80	7.56	7.86	2.82	10.68	7.39	18.07	3.98	10.04	6.13
0.82	7.75	7.58	2.84	10.43	7.22	17.65	3.95	9.92	5.82
0.84	7.94	7.32	2.86	10.18	7.06	17.24	3.93	9.79	5.52
0.86	8.14	7.06	2.88	9.94	6.91	16.85	3.90	9.67	5.24
0.88	8.33	6.82	2.90	9.71	6.75	16.46	3.87	9.54	4.97
0.90	8.53	6.58	2.91	9.49	6.60	16.10	3.84	9.42	4.72
0.92	8.72	6.35	2.93	9.28	6.46	15.74	3.82	9.31	4.48
0.94	8.92	6.14	2.95	9.08	6.32	15.40	3.79	9.19	4.25
0.96	9.11	5.93	2.96	8.89	6.18	15.07	3.76	9.08	4.04
0.98	9.31	5.73	2.98	8.71	6.04	14.75	3.73	8.96	3.83
1.00	9.51	5.53	3.00	8.53	5.91	14.45	3.70	8.85	3.64
1.02	9.70	5.35	3.01	8.36	5.79	14.15	3.67	8.75	3.45

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	9.90	5.17	3.03	8.20	5.68	13.88	3.63	8.64	3.28
1.06	10.10	5.00	3.05	8.04	5.57	13.61	3.59	8.53	3.11
1.08	10.30	4.83	3.06	7.90	5.47	13.36	3.54	8.43	2.96
1.10	10.50	4.67	3.08	7.75	5.37	13.12	3.50	8.33	2.81
1.12	10.70	4.52	3.09	7.61	5.28	12.89	3.45	8.23	2.67
1.14	10.90	4.37	3.11	7.48	5.19	12.67	3.41	8.13	2.53
1.16	11.11	4.23	3.12	7.35	5.10	12.46	3.36	8.03	2.41
1.18	11.31	4.09	3.14	7.23	5.02	12.25	3.31	7.93	2.28
1.20	11.51	3.96	3.15	7.11	4.94	12.06	3.26	7.84	2.17
1.22	11.71	3.83	3.17	7.00	4.87	11.87	3.22	7.75	2.06
1.24	11.92	3.71	3.18	6.89	4.80	11.69	3.17	7.65	1.96
1.26	12.12	3.59	3.20	6.79	4.73	11.52	3.12	7.56	1.86
1.28	12.33	3.48	3.21	6.69	4.66	11.35	3.08	7.47	1.77
1.30	12.53	3.37	3.23	6.59	4.59	11.19	3.03	7.39	1.68
1.32	12.74	3.26	3.24	6.50	4.53	11.03	3.00	7.30	1.60
1.34	12.95	3.16	3.25	6.41	4.47	10.88	3.00	7.21	1.52
1.36	13.16	3.06	3.27	6.33	4.41	10.73	3.00	7.13	1.44
1.38	13.36	2.97	3.28	6.25	4.35	10.60	3.00	7.05	1.37
1.40	13.57	2.88	3.30	6.18	4.29	10.46	3.00	6.97	1.31
1.42	13.78	2.79	3.32	6.11	4.23	10.34	3.00	6.89	1.24
1.44	13.99	2.71	3.33	6.04	4.17	10.21	3.00	6.81	1.19
1.46	14.20	2.63	3.35	5.98	4.12	10.10	3.00	6.74	1.13
1.48	14.41	2.55	3.37	5.92	4.06	9.98	3.00	6.66	1.08
1.50	14.62	2.48	3.39	5.86	4.01	9.87	3.00	6.59	1.03
1.52	14.84	2.41	3.41	5.81	3.95	9.77	3.00	6.52	0.98
1.54	15.05	2.34	3.42	5.76	3.90	9.66	3.00	6.44	0.94

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

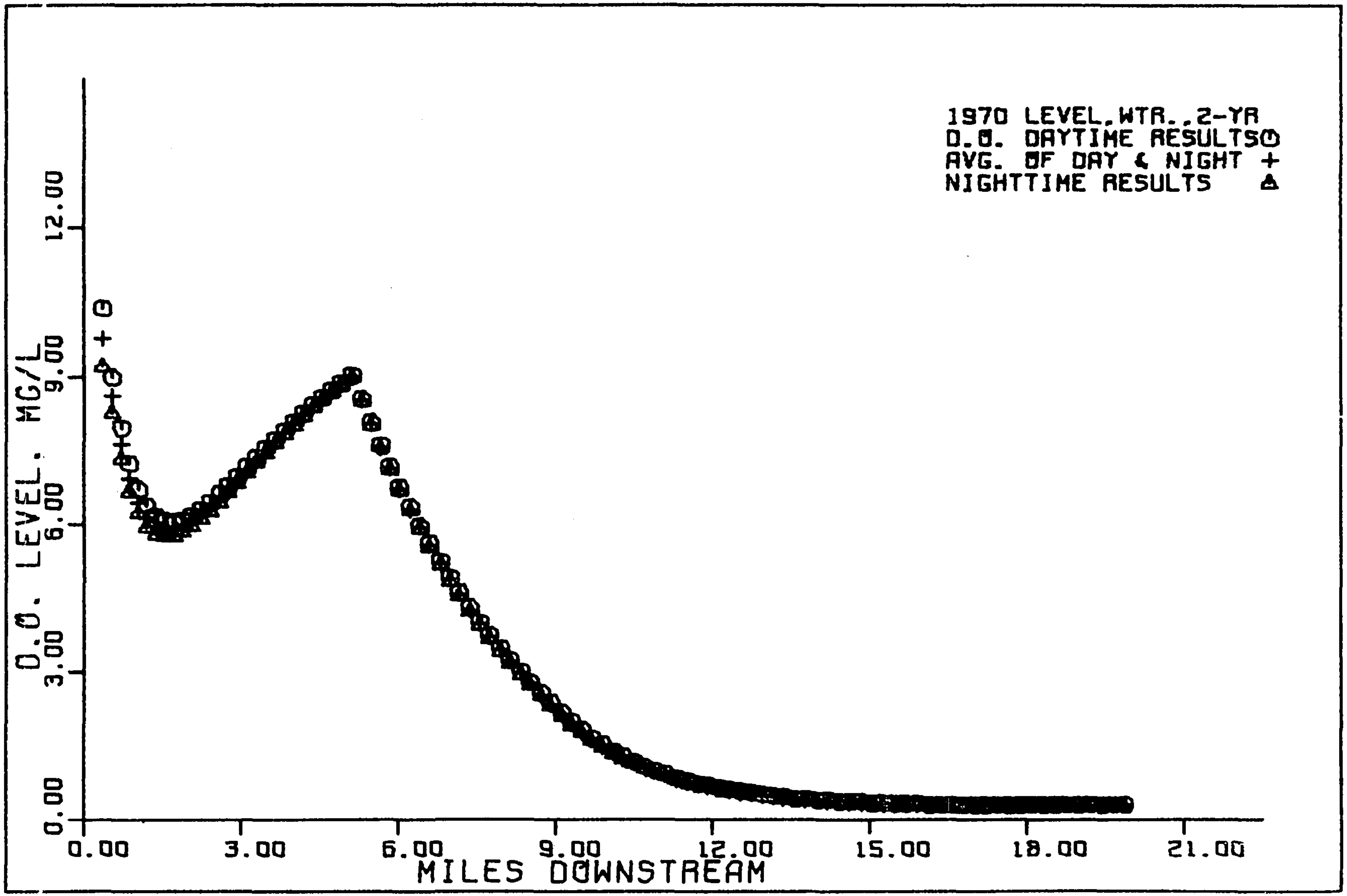
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	15.26	2.27	3.44	5.71	3.85	9.56	3.00	6.37	0.89
1.58	15.48	2.21	3.46	5.67	3.80	9.47	3.00	6.31	0.85
1.60	15.69	2.15	3.48	5.62	3.75	9.37	3.00	6.24	0.82
1.62	15.90	2.09	3.50	5.58	3.70	9.28	3.00	6.17	0.78
1.64	16.12	2.03	3.51	5.54	3.65	9.19	3.00	6.10	0.74
1.66	16.34	1.97	3.53	5.50	3.60	9.11	3.00	6.04	0.71
1.68	16.55	1.92	3.55	5.47	3.56	9.02	3.00	5.97	0.68
1.70	16.77	1.86	3.57	5.43	3.51	8.94	3.00	5.91	0.65
1.72	16.99	1.81	3.58	5.40	3.47	8.86	3.00	5.85	0.62
1.74	17.20	1.76	3.60	5.37	3.42	8.79	3.00	5.79	0.59
1.76	17.42	1.72	3.62	5.33	3.38	8.71	3.00	5.73	0.57
1.78	17.64	1.67	3.64	5.30	3.33	8.64	3.00	5.67	0.54
1.80	17.86	1.62	3.65	5.28	3.29	8.57	3.00	5.61	0.52
1.82	18.08	1.58	3.67	5.25	3.25	8.50	3.00	5.55	0.50
1.84	18.30	1.54	3.68	5.22	3.21	8.43	3.00	5.49	0.47
1.86	18.52	1.50	3.70	5.19	3.17	8.36	3.00	5.44	0.45
1.88	18.74	1.46	3.71	5.17	3.13	8.30	3.00	5.38	0.43
1.90	18.97	1.42	3.73	5.15	3.09	8.23	3.00	5.32	0.41
1.92	19.19	1.38	3.74	5.12	3.05	8.17	3.00	5.27	0.40
1.94	19.41	1.34	3.76	5.10	3.01	8.11	3.00	5.21	0.38
1.96	19.64	1.31	3.77	5.08	2.97	8.05	3.00	5.16	0.36
1.98	19.86	1.27	3.79	5.06	2.94	7.99	3.00	5.11	0.35

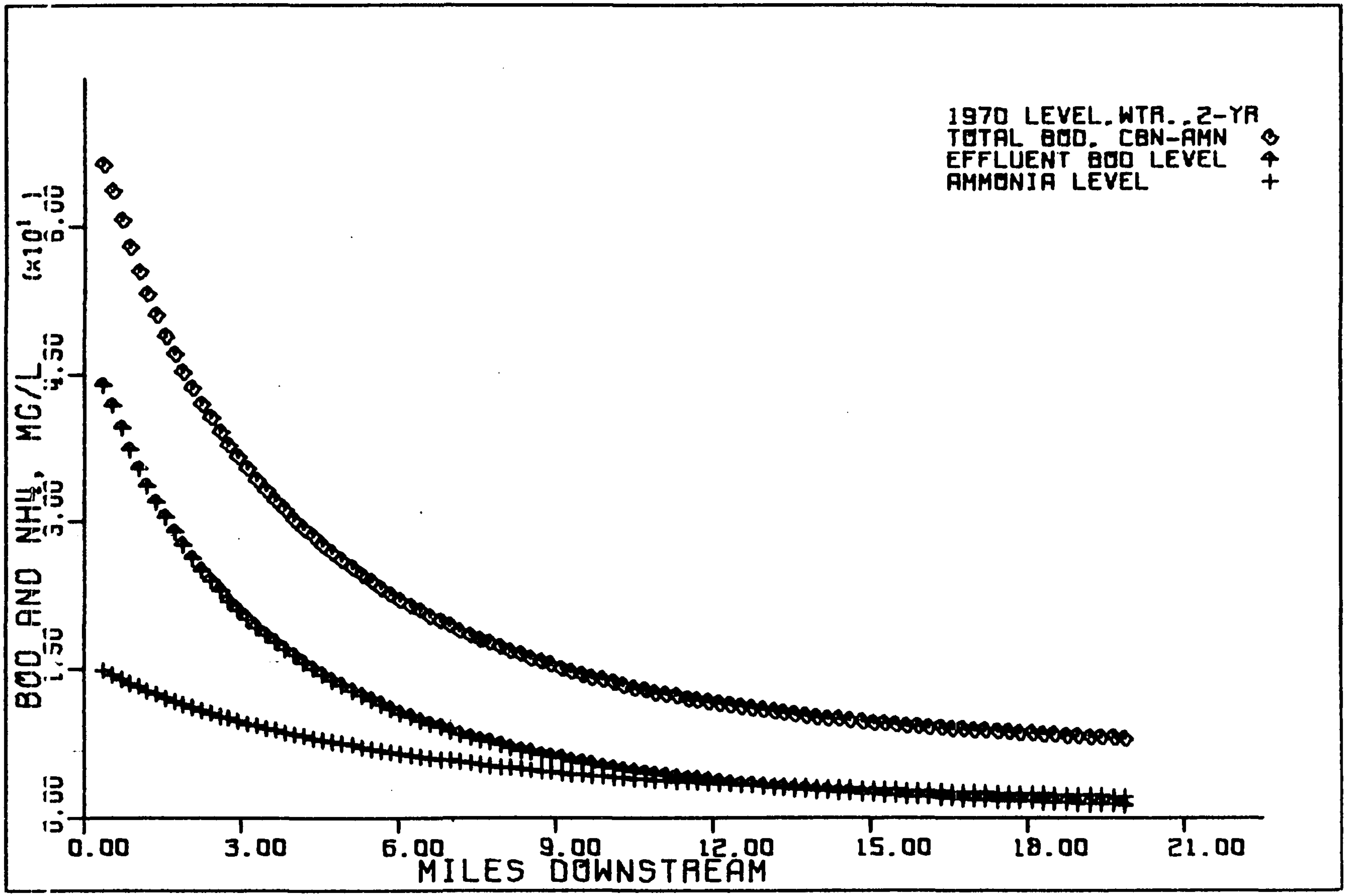
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE C.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	10.37	0.37	0.0	9.21	0.37	0.0
MINIMUM DO, MG/L	0.31	17.42	1.76	0.27	17.20	1.74
FINAL DO, MG/L	4.03	7.56	0.80	3.95	7.56	0.80
DO DEFICIT						
INITIAL, MG/L	1.75	0.37	0.0	2.91	0.37	0.0
FINAL, MG/L	10.16	7.56	0.80	10.24	7.56	0.80
RIVER DISCHARGE						
INITIAL, CFS	9.76	0.37	0.0	9.76	0.37	0.0
FINAL, CFS	14.07	7.56	0.80	14.07	7.56	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	42.62	0.37	0.0	42.62	0.37	0.0
FINAL, DEG F	32.11	7.56	0.80	32.11	7.56	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	43.99	0.37	0.0	43.99	0.37	0.0
FINAL BOD, MG/L	7.82	7.56	0.80	7.91	7.56	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.13	0.37	0.0	0.13	0.37	0.0
FINAL BOD IN RIVER	2.75	7.56	0.80	2.89	7.56	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	20.41	0.37	0.0	20.41	0.37	0.0
FINAL BOD, MG/L	7.39	7.56	0.80	7.39	7.56	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	65.91	0.37	0.0	66.69	0.37	0.0
FINAL VALUE, MG/L	17.96	7.56	0.80	18.19	7.56	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	14.92	0.37	0.0	14.92	0.37	0.0
FINAL VALUE, MG/L	5.40	7.56	0.80	5.40	7.56	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.18	0.37	0.0	4.18	0.37	0.0
FINAL VALUE, MG/L	3.98	7.56	0.80	3.98	7.56	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	17.87	0.37	0.0	17.87	0.37	0.0
FINAL VALUE, MG/L	10.04	7.56	0.80	10.04	7.56	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	59.05	0.37	0.0	59.05	0.37	0.0
FINAL PERCENT	6.13	7.56	0.80	6.13	7.56	0.80


1970 LEVEL.WTR..2-YR
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL. MG/L
0.00
3.00
6.00
9.00
12.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
MILES DOWNSTREAM



1970 LEVEL.WTR..2-YR
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10^1)
0.00
1.50
3.00
4.50
6.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
MILES DOWNSTREAM

E. Computer Results for 1970 Status Study, Winter, 2 Yr,

High Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.72	50.00	75.00	0.0	55.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	95.00	75.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
4.00	0.60	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2P
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.300	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDOCY	DLOCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                    AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

      INPUT DATA FOR THIS ANALYSIS

      STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
      RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
      SEASON : WINTER

 GAMMA1 =   0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    5.76 CFS, RIVER Q =    4.00 CFS, TOTAL Q =    9.76 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
```

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		4.0	13.50	10.66		0.40
0.0	0.37	42.6	42.6	42.6	9.8	10.37	9.21	9.79	14.92
0.02	0.54	41.5	41.5	41.5	9.9	8.99	8.25	8.62	14.42
0.04	0.71	40.4	40.4	40.4	10.0	7.96	7.31	7.64	13.97
0.06	0.87	39.5	39.5	39.5	10.1	7.22	6.66	6.94	13.54
0.08	1.04	38.7	38.7	38.7	10.2	6.71	6.22	6.46	13.13
0.10	1.21	38.0	38.0	38.0	10.3	6.38	5.94	6.16	12.75
0.12	1.38	37.3	37.3	37.3	10.4	6.18	5.79	5.98	12.38
0.14	1.56	36.7	36.7	36.7	10.5	6.08	5.74	5.91	12.04
0.16	1.73	36.2	36.2	36.2	10.6	6.06	5.75	5.91	11.71
0.18	1.90	35.8	35.8	35.8	10.7	6.10	5.83	5.96	11.39
0.20	2.07	35.4	35.4	35.4	10.8	6.19	5.94	6.07	11.09
0.22	2.25	35.0	35.0	35.0	10.9	6.31	6.09	6.20	10.80
0.24	2.42	34.7	34.7	34.7	11.0	6.45	6.26	6.36	10.52
0.26	2.60	34.4	34.4	34.4	11.1	6.62	6.44	6.53	10.25
0.28	2.77	34.1	34.1	34.1	11.2	6.79	6.63	6.71	9.99
0.30	2.95	33.9	33.9	33.9	11.3	6.97	6.83	6.90	9.74
0.32	3.13	33.7	33.7	33.7	11.4	7.16	7.03	7.10	9.50
0.34	3.30	33.5	33.5	33.5	11.5	7.35	7.23	7.29	9.27
0.36	3.48	33.3	33.3	33.3	11.6	7.54	7.43	7.48	9.04
0.38	3.66	33.2	33.2	33.2	11.7	7.72	7.62	7.67	8.82
0.40	3.84	33.1	33.1	33.1	11.8	7.90	7.81	7.86	8.61
0.42	4.02	32.9	32.9	32.9	11.9	8.08	8.00	8.04	8.40
0.44	4.20	32.8	32.8	32.8	12.1	8.26	8.18	8.22	8.20
0.46	4.38	32.8	32.8	32.8	12.2	8.42	8.35	8.39	8.01
0.48	4.57	32.7	32.7	32.7	12.3	8.59	8.52	8.55	7.82
0.50	4.75	32.6	32.6	32.6	12.4	8.74	8.68	8.71	7.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.93	32.5	32.5	32.5	12.5	8.89	8.84	8.86	7.46
0.54	5.12	32.5	32.5	32.5	12.6	9.04	8.99	9.01	7.28
0.56	5.30	32.4	32.4	32.4	12.7	8.56	8.50	8.53	7.11
0.58	5.48	32.4	32.4	32.4	12.8	8.11	8.04	8.08	6.95
0.60	5.67	32.3	32.3	32.3	12.9	7.67	7.61	7.64	6.79
0.62	5.86	32.3	32.3	32.3	13.1	7.27	7.20	7.23	6.63
0.64	6.04	32.3	32.3	32.3	13.2	6.88	6.81	6.84	6.48
0.66	6.23	32.2	32.2	32.2	13.3	6.51	6.44	6.47	6.33
0.68	6.42	32.2	32.2	32.2	13.4	6.16	6.09	6.13	6.19
0.70	6.61	32.2	32.2	32.2	13.5	5.83	5.76	5.80	6.05
0.72	6.80	32.2	32.2	32.2	13.6	5.52	5.45	5.48	5.91
0.74	6.99	32.2	32.2	32.2	13.7	5.23	5.15	5.19	5.78
0.76	7.18	32.1	32.1	32.1	13.8	4.95	4.87	4.91	5.65
0.78	7.37	32.1	32.1	32.1	14.0	4.68	4.61	4.64	5.52
0.80	7.56	32.1	32.1	32.1	14.1	4.43	4.36	4.39	5.40
0.82	7.75	32.1	32.1	32.1	14.2	4.20	4.12	4.16	5.28
0.84	7.94	32.1	32.1	32.1	14.3	3.98	3.90	3.94	5.16
0.86	8.14	32.1	32.1	32.1	14.4	3.77	3.69	3.73	5.05
0.88	8.33	32.1	32.1	32.1	14.5	3.57	3.49	3.53	4.94
0.90	8.53	32.1	32.1	32.1	14.7	3.38	3.30	3.34	4.83
0.92	8.72	32.1	32.1	32.1	14.8	3.21	3.13	3.17	4.72
0.94	8.92	32.0	32.0	32.0	14.9	3.05	2.97	3.01	4.62
0.96	9.11	32.0	32.0	32.0	15.0	2.89	2.81	2.85	4.52
0.98	9.31	32.0	32.0	32.0	15.1	2.75	2.67	2.71	4.42
1.00	9.51	32.0	32.0	32.0	15.2	2.61	2.53	2.57	4.32
1.02	9.70	32.0	32.0	32.0	15.4	2.49	2.41	2.45	4.23

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	9.90	32.0	32.0	32.0	15.5	2.37	2.29	2.33	4.14
1.06	10.10	32.0	32.0	32.0	15.6	2.26	2.18	2.22	4.05
1.08	10.30	32.0	32.0	32.0	15.7	2.16	2.08	2.12	3.96
1.10	10.50	32.0	32.0	32.0	15.8	2.06	1.98	2.02	3.87
1.12	10.70	32.0	32.0	32.0	16.0	1.97	1.90	1.94	3.79
1.14	10.90	32.0	32.0	32.0	16.1	1.89	1.82	1.86	3.71
1.16	11.11	32.0	32.0	32.0	16.2	1.82	1.75	1.79	3.63
1.18	11.31	32.0	32.0	32.0	16.3	1.76	1.69	1.73	3.56
1.20	11.51	32.0	32.0	32.0	16.4	1.71	1.64	1.67	3.49
1.22	11.71	32.0	32.0	32.0	16.6	1.66	1.60	1.63	3.42
1.24	11.92	32.0	32.0	32.0	16.7	1.62	1.56	1.59	3.36
1.26	12.12	32.0	32.0	32.0	16.8	1.58	1.53	1.55	3.29
1.28	12.33	32.0	32.0	32.0	16.9	1.55	1.50	1.52	3.23
1.30	12.53	32.0	32.0	32.0	17.1	1.53	1.47	1.50	3.17
1.32	12.74	32.0	32.0	32.0	17.2	1.51	1.46	1.48	3.11
1.34	12.95	32.0	32.0	32.0	17.3	1.49	1.44	1.46	3.05
1.36	13.16	32.0	32.0	32.0	17.4	1.47	1.43	1.45	3.00
1.38	13.36	32.0	32.0	32.0	17.6	1.46	1.42	1.44	2.94
1.40	13.57	32.0	32.0	32.0	17.7	1.46	1.41	1.43	2.89
1.42	13.78	32.0	32.0	32.0	17.8	1.45	1.41	1.43	2.84
1.44	13.99	32.0	32.0	32.0	17.9	1.45	1.41	1.43	2.79
1.46	14.20	32.0	32.0	32.0	18.1	1.45	1.41	1.43	2.74
1.48	14.41	32.0	32.0	32.0	18.2	1.45	1.41	1.43	2.69
1.50	14.62	32.0	32.0	32.0	18.3	1.46	1.42	1.44	2.64
1.52	14.84	32.0	32.0	32.0	18.4	1.46	1.42	1.44	2.59
1.54	15.05	32.0	32.0	32.0	18.6	1.47	1.43	1.45	2.55

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	15.26	32.0	32.0	32.0	18.7	1.48	1.44	1.46	2.50
1.58	15.48	32.0	32.0	32.0	18.8	1.48	1.45	1.47	2.46
1.60	15.69	32.0	32.0	32.0	19.0	1.50	1.46	1.48	2.41
1.62	15.90	32.0	32.0	32.0	19.1	1.51	1.47	1.49	2.37
1.64	16.12	32.0	32.0	32.0	19.2	1.52	1.49	1.50	2.33
1.66	16.34	32.0	32.0	32.0	19.3	1.53	1.50	1.52	2.29
1.68	16.55	32.0	32.0	32.0	19.5	1.55	1.51	1.53	2.25
1.70	16.77	32.0	32.0	32.0	19.6	1.56	1.53	1.55	2.21
1.72	16.99	32.0	32.0	32.0	19.7	1.58	1.55	1.56	2.17
1.74	17.20	32.0	32.0	32.0	19.9	1.59	1.56	1.58	2.13
1.76	17.42	32.0	32.0	32.0	20.0	1.61	1.58	1.59	2.09
1.78	17.64	32.0	32.0	32.0	20.1	1.62	1.59	1.61	2.05
1.80	17.86	32.0	32.0	32.0	20.3	1.64	1.61	1.62	2.01
1.82	18.08	32.0	32.0	32.0	20.4	1.65	1.63	1.64	1.98
1.84	18.30	32.0	32.0	32.0	20.5	1.67	1.64	1.66	1.94
1.86	18.52	32.0	32.0	32.0	20.7	1.69	1.66	1.67	1.91
1.88	18.74	32.0	32.0	32.0	20.8	1.70	1.68	1.69	1.87
1.90	18.97	32.0	32.0	32.0	20.9	1.72	1.69	1.71	1.84
1.92	19.19	32.0	32.0	32.0	21.1	1.74	1.71	1.72	1.80
1.94	19.41	32.0	32.0	32.0	21.2	1.75	1.73	1.74	1.77
1.96	19.64	32.0	32.0	32.0	21.3	1.77	1.74	1.76	1.74
1.98	19.86	32.0	32.0	32.0	21.5	1.79	1.76	1.77	1.71

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER					NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
		EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L			
0.0	0.0	2.00	1.52	3.52	0.55	4.06	3.00	0.40	0.10
0.0	0.37	43.99	1.93	45.92	20.41	66.32	4.18	17.87	59.05
0.02	0.54	41.90	1.97	43.87	19.73	63.61	4.24	17.55	55.07
0.04	0.71	39.57	1.99	41.56	19.10	60.66	4.30	17.25	51.46
0.06	0.87	37.43	2.00	39.44	18.52	57.95	4.34	16.96	48.17
0.08	1.04	35.47	2.02	37.49	17.96	55.45	4.38	16.68	45.15
0.10	1.21	33.66	2.04	35.70	17.44	53.14	4.40	16.41	42.38
0.12	1.38	31.98	2.07	34.04	16.94	50.98	4.43	16.15	39.82
0.14	1.56	30.41	2.09	32.50	16.47	48.97	4.45	15.89	37.46
0.16	1.73	28.96	2.11	31.07	16.02	47.09	4.46	15.65	35.27
0.18	1.90	27.60	2.14	29.73	15.59	45.32	4.47	15.41	33.23
0.20	2.07	26.32	2.16	28.48	15.17	43.66	4.48	15.17	31.33
0.22	2.25	25.13	2.19	27.31	14.77	42.09	4.48	14.95	29.56
0.24	2.42	24.00	2.21	26.21	14.39	40.60	4.48	14.72	27.90
0.26	2.60	22.94	2.24	25.18	14.03	39.20	4.48	14.51	26.35
0.28	2.77	21.94	2.26	24.20	13.67	37.87	4.48	14.30	24.89
0.30	2.95	21.00	2.29	23.28	13.33	36.61	4.47	14.09	23.53
0.32	3.13	20.10	2.31	22.41	13.00	35.41	4.47	13.89	22.25
0.34	3.30	19.26	2.34	21.59	12.68	34.27	4.46	13.69	21.04
0.36	3.48	18.46	2.36	20.82	12.37	33.18	4.45	13.50	19.91
0.38	3.66	17.69	2.38	20.08	12.07	32.15	4.43	13.31	18.84
0.40	3.84	16.97	2.41	19.38	11.78	31.16	4.42	13.12	17.83
0.42	4.02	16.29	2.43	18.72	11.49	30.21	4.41	12.94	16.89
0.44	4.20	15.63	2.45	18.09	11.22	29.31	4.39	12.76	15.99
0.46	4.38	15.01	2.48	17.49	10.95	28.44	4.37	12.59	15.15
0.48	4.57	14.42	2.50	16.92	10.70	27.62	4.36	12.41	14.35
0.50	4.75	13.86	2.52	16.38	10.44	26.82	4.34	12.24	13.59

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.93	13.32	2.55	15.86	10.20	26.06	4.32	12.08	12.88
0.54	5.12	12.80	2.57	15.37	9.96	25.33	4.30	11.92	12.21
0.56	5.30	12.31	2.59	14.90	9.73	24.63	4.28	11.76	11.57
0.58	5.48	11.85	2.61	14.46	9.51	23.96	4.25	11.60	10.97
0.60	5.67	11.40	2.63	14.03	9.29	23.32	4.23	11.45	10.40
0.62	5.86	10.97	2.65	13.62	9.07	22.70	4.21	11.29	9.86
0.64	6.04	10.56	2.67	13.24	8.87	22.10	4.18	11.15	9.35
0.66	6.23	10.17	2.69	12.87	8.66	21.53	4.16	11.00	8.87
0.68	6.42	9.80	2.71	12.51	8.47	20.98	4.14	10.86	8.41
0.70	6.61	9.44	2.73	12.17	8.28	20.45	4.11	10.71	7.98
0.72	6.80	9.10	2.75	11.85	8.09	19.94	4.09	10.58	7.57
0.74	6.99	8.77	2.77	11.54	7.91	19.45	4.06	10.44	7.18
0.76	7.18	8.45	2.79	11.24	7.73	18.97	4.03	10.30	6.81
0.78	7.37	8.15	2.81	10.96	7.56	18.52	4.01	10.17	6.46
0.80	7.56	7.86	2.83	10.69	7.39	18.08	3.98	10.04	6.13
0.82	7.75	7.59	2.85	10.43	7.22	17.65	3.95	9.92	5.82
0.84	7.94	7.32	2.86	10.18	7.06	17.24	3.93	9.79	5.52
0.86	8.14	7.06	2.88	9.94	6.91	16.85	3.90	9.67	5.24
0.88	8.33	6.82	2.90	9.72	6.75	16.47	3.87	9.54	4.97
0.90	8.53	6.58	2.92	9.50	6.60	16.10	3.84	9.42	4.72
0.92	8.72	6.36	2.93	9.29	6.46	15.75	3.82	9.31	4.48
0.94	8.92	6.14	2.95	9.09	6.32	15.41	3.79	9.19	4.25
0.96	9.11	5.93	2.97	8.90	6.18	15.08	3.76	9.08	4.04
0.98	9.31	5.73	2.98	8.71	6.04	14.76	3.73	8.96	3.83
1.00	9.51	5.54	3.00	8.54	5.91	14.45	3.70	8.85	3.64
1.02	9.70	5.35	3.02	8.37	5.78	14.15	3.68	8.75	3.45

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	9.90	5.17	3.03	8.20	5.66	13.86	3.65	8.64	3.28
1.06	10.10	5.00	3.05	8.05	5.54	13.58	3.62	8.53	3.11
1.08	10.30	4.83	3.07	7.90	5.42	13.32	3.59	8.43	2.96
1.10	10.50	4.67	3.08	7.76	5.30	13.06	3.56	8.33	2.81
1.12	10.70	4.52	3.10	7.62	5.19	12.80	3.54	8.23	2.67
1.14	10.90	4.37	3.11	7.49	5.08	12.56	3.51	8.13	2.53
1.16	11.11	4.23	3.13	7.36	4.97	12.33	3.47	8.03	2.41
1.18	11.31	4.09	3.14	7.24	4.87	12.11	3.44	7.93	2.28
1.20	11.51	3.96	3.16	7.12	4.77	11.89	3.41	7.84	2.17
1.22	11.71	3.83	3.17	7.01	4.68	11.69	3.37	7.75	2.06
1.24	11.92	3.71	3.19	6.90	4.59	11.49	3.34	7.65	1.96
1.26	12.12	3.59	3.20	6.80	4.50	11.30	3.30	7.56	1.86
1.28	12.33	3.48	3.22	6.70	4.42	11.11	3.26	7.47	1.77
1.30	12.53	3.37	3.23	6.60	4.33	10.93	3.23	7.39	1.68
1.32	12.74	3.26	3.24	6.51	4.25	10.76	3.19	7.30	1.60
1.34	12.95	3.16	3.26	6.42	4.18	10.60	3.15	7.21	1.52
1.36	13.16	3.06	3.27	6.34	4.10	10.43	3.12	7.13	1.44
1.38	13.36	2.97	3.29	6.25	4.02	10.28	3.08	7.05	1.37
1.40	13.57	2.88	3.30	6.18	3.95	10.13	3.05	6.97	1.30
1.42	13.78	2.79	3.31	6.10	3.88	9.98	3.01	6.89	1.24
1.44	13.99	2.70	3.33	6.03	3.81	9.84	3.00	6.81	1.18
1.46	14.20	2.62	3.34	5.96	3.74	9.70	3.00	6.73	1.12
1.48	14.41	2.54	3.35	5.89	3.68	9.57	3.00	6.65	1.06
1.50	14.62	2.46	3.37	5.83	3.61	9.44	3.00	6.57	1.01
1.52	14.84	2.39	3.38	5.77	3.55	9.31	3.00	6.50	0.96
1.54	15.05	2.31	3.39	5.71	3.48	9.19	3.00	6.43	0.91

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	15.26	2.24	3.41	5.65	3.42	9.07	3.00	6.35	0.87
1.58	15.48	2.18	3.42	5.59	3.36	8.95	3.00	6.28	0.83
1.60	15.69	2.11	3.43	5.54	3.30	8.84	3.00	6.21	0.79
1.62	15.90	2.05	3.44	5.49	3.24	8.73	3.00	6.14	0.75
1.64	16.12	1.99	3.46	5.44	3.18	8.63	3.00	6.07	0.71
1.66	16.34	1.93	3.47	5.40	3.13	8.52	3.00	6.01	0.68
1.68	16.55	1.87	3.48	5.35	3.07	8.42	3.00	5.94	0.64
1.70	16.77	1.81	3.49	5.31	3.02	8.32	3.00	5.87	0.61
1.72	16.99	1.76	3.50	5.27	2.96	8.23	3.00	5.81	0.58
1.74	17.20	1.71	3.52	5.23	2.91	8.14	3.00	5.74	0.55
1.76	17.42	1.66	3.53	5.19	2.86	8.05	3.00	5.68	0.53
1.78	17.64	1.61	3.54	5.15	2.81	7.96	3.00	5.62	0.50
1.80	17.86	1.56	3.55	5.12	2.76	7.87	3.00	5.56	0.48
1.82	18.08	1.52	3.56	5.08	2.71	7.79	3.00	5.50	0.45
1.84	18.30	1.47	3.57	5.05	2.66	7.71	3.00	5.44	0.43
1.86	18.52	1.43	3.59	5.02	2.61	7.63	3.00	5.38	0.41
1.88	18.74	1.39	3.60	4.99	2.56	7.55	3.00	5.32	0.39
1.90	18.97	1.35	3.61	4.96	2.51	7.47	3.00	5.26	0.37
1.92	19.19	1.31	3.62	4.93	2.47	7.40	3.00	5.20	0.36
1.94	19.41	1.27	3.63	4.91	2.42	7.33	3.00	5.15	0.34
1.96	19.64	1.24	3.64	4.88	2.38	7.26	3.00	5.09	0.32
1.98	19.86	1.20	3.65	4.86	2.34	7.19	3.00	5.04	0.31

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 2-YR LOW FLOW FREQ
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	10.37	0.37	0.0	9.21	0.37	0.0
MINIMUM DO, MG/L	1.45	14.20	1.46	1.41	13.99	1.44
FINAL DO, MG/L	4.43	7.56	0.80	4.36	7.56	0.80
DO DEFICIT						
INITIAL, MG/L	1.75	0.37	0.0	2.91	0.37	0.0
FINAL, MG/L	9.76	7.56	0.80	9.83	7.56	0.80
RIVER DISCHARGE						
INITIAL, CFS	9.76	0.37	0.0	9.76	0.37	0.0
FINAL, CFS	14.07	7.56	0.80	14.07	7.56	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	42.62	0.37	0.0	42.62	0.37	0.0
FINAL, DEG F	32.11	7.56	0.80	32.11	7.56	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	43.99	0.37	0.0	43.99	0.37	0.0
FINAL BOD, MG/L	7.82	7.56	0.80	7.91	7.56	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.13	0.37	0.0	0.13	0.37	0.0
FINAL BOD IN RIVER	2.75	7.56	0.80	2.90	7.56	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	20.41	0.37	0.0	20.41	0.37	0.0
FINAL BOD, MG/L	7.39	7.56	0.80	7.39	7.56	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	65.91	0.37	0.0	66.74	0.37	0.0
FINAL VALUE, MG/L	17.96	7.56	0.80	18.20	7.56	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	14.92	0.37	0.0	14.92	0.37	0.0
FINAL VALUE, MG/L	5.40	7.56	0.80	5.40	7.56	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.18	0.37	0.0	4.18	0.37	0.0
FINAL VALUE, MG/L	3.98	7.56	0.80	3.98	7.56	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	17.87	0.37	0.0	17.87	0.37	0.0
FINAL VALUE, MG/L	10.04	7.56	0.80	10.04	7.56	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	59.05	0.37	0.0	59.05	0.37	0.0
FINAL PERCENT	6.13	7.56	0.80	6.13	7.56	0.80

F. Computer Results for 1970 Status Study, August, 10 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
4.55	70.00	75.00	0.0	40.00	0.080	0.0	12.00	12.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
88.00	73.00	120.00	75.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	50.00	2.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
5.00	0.60	105.00	60.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2P
88.00	73.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	2.00	3.00	3.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDOCY	DLOCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
     SEASON : AUGUST

 GAMMA1 =    0.80  , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   2.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   7.04 CFS, RIVER Q =   5.00 CFS, TOTAL Q =  12.04 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   1.00 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	88.0	73.0		5.0	8.48	6.21		0.40
0.0	0.37	77.5	71.2	74.4	12.0	7.27	6.33	6.80	7.18
0.01	0.46	78.1	71.3	74.7	12.1	6.21	5.42	5.82	6.83
0.02	0.55	78.6	71.4	75.0	12.2	5.32	4.42	4.87	6.48
0.03	0.64	79.1	71.5	75.3	12.2	4.60	3.58	4.09	6.15
0.04	0.73	79.6	71.6	75.6	12.3	4.05	2.88	3.46	5.83
0.05	0.82	80.1	71.7	75.9	12.3	3.64	2.29	2.97	5.53
0.06	0.92	80.5	71.8	76.2	12.4	3.36	1.81	2.59	5.24
0.07	1.01	81.0	71.8	76.4	12.4	3.21	1.44	2.32	4.97
0.08	1.10	81.4	71.9	76.6	12.5	3.16	1.19	2.18	4.72
0.09	1.19	81.7	72.0	76.8	12.5	3.21	1.03	2.12	4.49
0.10	1.28	82.1	72.0	77.0	12.6	3.34	0.91	2.13	4.28
0.11	1.38	82.4	72.1	77.2	12.6	3.55	0.84	2.19	4.08
0.12	1.47	82.7	72.1	77.4	12.7	3.82	0.79	2.30	3.90
0.13	1.56	83.0	72.2	77.6	12.8	4.15	0.76	2.45	3.72
0.14	1.65	83.3	72.2	77.8	12.8	4.52	0.74	2.63	3.55
0.15	1.75	83.6	72.3	77.9	12.9	4.93	0.73	2.83	3.39
0.16	1.84	83.8	72.3	78.1	12.9	5.36	0.73	3.05	3.24
0.17	1.93	84.0	72.3	78.2	13.0	5.82	0.73	3.28	3.10
0.18	2.02	84.3	72.4	78.3	13.0	6.29	0.74	3.52	2.96
0.19	2.12	84.5	72.4	78.4	13.1	6.77	0.76	3.76	2.83
0.20	2.21	84.7	72.4	78.6	13.1	7.24	0.77	4.01	2.70
0.21	2.31	84.9	72.5	78.7	13.2	7.71	0.80	4.25	2.59
0.22	2.40	85.0	72.5	78.8	13.3	8.17	0.82	4.49	2.47
0.23	2.49	85.2	72.5	78.9	13.3	8.60	0.85	4.73	2.37
0.24	2.59	85.4	72.6	79.0	13.4	9.02	0.88	4.95	2.26
0.25	2.68	85.5	72.6	79.0	13.4	9.41	0.92	5.16	2.16

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.78	85.6	72.6	79.1	13.5	9.76	0.96	5.36	2.07
0.27	2.87	85.8	72.6	79.2	13.5	10.08	1.00	5.54	1.98
0.28	2.96	85.9	72.6	79.3	13.6	10.37	1.05	5.71	1.89
0.29	3.06	86.0	72.7	79.3	13.7	10.61	1.10	5.86	1.81
0.30	3.15	86.1	72.7	79.4	13.7	10.82	1.15	5.99	1.73
0.31	3.25	86.2	72.7	79.5	13.8	10.99	1.21	6.10	1.65
0.32	3.35	86.3	72.7	79.5	13.8	11.11	1.28	6.19	1.58
0.33	3.44	86.4	72.7	79.6	13.9	11.20	1.34	6.27	1.51
0.34	3.54	86.5	72.8	79.6	13.9	11.24	1.42	6.33	1.44
0.35	3.63	86.6	72.8	79.7	14.0	11.25	1.50	6.37	1.38
0.36	3.73	86.7	72.8	79.7	14.1	11.22	1.58	6.40	1.31
0.37	3.82	86.7	72.8	79.8	14.1	11.16	1.67	6.42	1.25
0.38	3.92	86.8	72.8	79.8	14.2	11.07	1.77	6.42	1.19
0.39	4.02	86.9	72.8	79.8	14.2	10.96	1.88	6.42	1.13
0.40	4.11	86.9	72.8	79.9	14.3	10.81	1.99	6.40	1.09
0.41	4.21	87.0	72.8	79.9	14.3	10.65	2.11	6.38	1.05
0.42	4.31	87.1	72.8	80.0	14.4	10.48	2.24	6.36	1.01
0.43	4.40	87.1	72.9	80.0	14.5	10.29	2.39	6.34	0.97
0.44	4.50	87.2	72.9	80.0	14.5	10.10	2.54	6.32	0.94
0.45	4.60	87.2	72.9	80.0	14.6	9.91	2.70	6.31	0.90
0.46	4.69	87.3	72.9	80.1	14.6	9.72	2.87	6.29	0.87
0.47	4.79	87.3	72.9	80.1	14.7	9.53	3.05	6.29	0.84
0.48	4.89	87.3	72.9	80.1	14.8	9.35	3.22	6.29	0.81
0.49	4.99	87.4	72.9	80.1	14.8	9.19	3.39	6.29	0.78
0.50	5.09	87.4	72.9	80.2	14.9	9.05	3.55	6.30	0.76
0.51	5.18	87.4	72.9	80.2	14.9	8.93	3.70	6.31	0.73

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	5.28	87.5	72.9	80.2	15.0	8.83	3.84	6.33	0.71
0.53	5.38	87.5	72.9	80.2	15.0	8.75	3.97	6.36	0.69
0.54	5.48	87.5	72.9	80.2	15.1	8.68	4.08	6.38	0.66
0.55	5.58	87.6	72.9	80.2	15.2	8.62	4.19	6.41	0.64
0.56	5.68	87.6	72.9	80.3	15.2	8.58	4.30	6.44	0.62
0.57	5.77	87.6	72.9	80.3	15.3	8.54	4.39	6.47	0.61
0.58	5.87	87.6	72.9	80.3	15.3	8.51	4.48	6.50	0.59
0.59	5.97	87.6	72.9	80.3	15.4	8.49	4.56	6.53	0.57
0.60	6.07	87.7	72.9	80.3	15.5	8.47	4.64	6.55	0.55
0.61	6.17	87.7	72.9	80.3	15.5	8.46	4.71	6.58	0.54
0.62	6.27	87.7	73.0	80.3	15.6	8.45	4.78	6.61	0.52
0.63	6.37	87.7	73.0	80.3	15.6	8.44	4.84	6.64	0.51
0.64	6.47	87.7	73.0	80.3	15.7	8.43	4.90	6.67	0.50
0.65	6.57	87.7	73.0	80.4	15.8	8.43	4.95	6.69	0.48
0.66	6.67	87.8	73.0	80.4	15.8	8.43	5.01	6.72	0.47
0.67	6.77	87.8	73.0	80.4	15.9	8.43	5.05	6.74	0.46
0.68	6.87	87.8	73.0	80.4	15.9	8.43	5.10	6.77	0.45
0.69	6.97	87.8	73.0	80.4	16.0	8.43	5.14	6.79	0.44
0.70	7.07	87.8	73.0	80.4	16.1	8.43	5.18	6.81	0.43
0.71	7.17	87.8	73.0	80.4	16.1	8.44	5.22	6.83	0.42
0.72	7.28	87.8	73.0	80.4	16.2	8.44	5.26	6.85	0.41
0.73	7.38	87.8	73.0	80.4	16.2	8.44	5.29	6.87	0.40
0.74	7.48	87.9	73.0	80.4	16.3	8.45	5.33	6.89	0.40
0.75	7.58	87.9	73.0	80.4	16.4	8.45	5.36	6.90	0.40
0.76	7.68	87.9	73.0	80.4	16.4	8.45	5.39	6.92	0.40
0.77	7.78	87.9	73.0	80.4	16.5	8.46	5.41	6.94	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	7.89	87.9	73.0	80.4	16.6	8.46	5.44	6.95	0.40
0.79	7.99	87.9	73.0	80.4	16.6	8.47	5.46	6.96	0.40
0.80	8.09	87.9	73.0	80.4	16.7	8.47	5.49	6.98	0.40
0.81	8.19	87.9	73.0	80.4	16.7	8.47	5.51	6.99	0.40
0.82	8.29	87.9	73.0	80.4	16.8	8.48	5.53	7.00	0.40
0.83	8.40	87.9	73.0	80.4	16.9	8.48	5.55	7.02	0.40
0.84	8.50	87.9	73.0	80.5	16.9	8.48	5.57	7.03	0.40
0.85	8.60	87.9	73.0	80.5	17.0	8.48	5.59	7.04	0.40
0.86	8.71	87.9	73.0	80.5	17.0	8.49	5.61	7.05	0.40
0.87	8.81	87.9	73.0	80.5	17.1	8.49	5.62	7.06	0.40
0.88	8.91	87.9	73.0	80.5	17.2	8.49	5.64	7.07	0.40
0.89	9.02	87.9	73.0	80.5	17.2	8.49	5.65	7.07	0.40
0.90	9.12	87.9	73.0	80.5	17.3	8.50	5.67	7.08	0.40
0.91	9.22	87.9	73.0	80.5	17.4	8.50	5.68	7.09	0.40
0.92	9.33	87.9	73.0	80.5	17.4	8.50	5.69	7.10	0.40
0.93	9.43	87.9	73.0	80.5	17.5	8.50	5.71	7.10	0.40
0.94	9.54	88.0	73.0	80.5	17.5	8.51	5.72	7.11	0.40
0.95	9.64	88.0	73.0	80.5	17.6	8.51	5.73	7.12	0.40
0.96	9.74	88.0	73.0	80.5	17.7	8.51	5.74	7.12	0.40
0.97	9.85	88.0	73.0	80.5	17.7	8.51	5.75	7.13	0.40
0.98	9.95	88.0	73.0	80.5	17.8	8.51	5.76	7.14	0.40
0.99	10.06	88.0	73.0	80.5	17.9	8.51	5.77	7.14	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	1.79	3.78	0.55	4.33	3.00	0.40	0.10
0.0	0.37	31.94	2.52	34.46	9.83	44.29	8.26	14.79	58.52
0.01	0.46	30.62	2.50	33.12	9.34	42.46	8.03	14.50	54.27
0.02	0.55	28.98	2.45	31.43	8.87	40.30	7.79	14.21	50.29
0.03	0.64	27.44	2.40	29.84	8.42	38.26	7.56	13.93	46.57
0.04	0.73	25.98	2.36	28.34	7.98	36.32	7.32	13.65	43.10
0.05	0.82	24.61	2.32	26.93	7.57	34.49	7.09	13.37	39.86
0.06	0.92	23.31	2.28	25.59	7.17	32.76	6.86	13.09	36.86
0.07	1.01	22.09	2.24	24.33	6.79	31.13	6.63	12.82	34.06
0.08	1.10	20.94	2.21	23.15	6.46	29.61	6.38	12.55	31.46
0.09	1.19	19.86	2.18	22.03	6.15	28.18	6.12	12.29	29.04
0.10	1.28	18.83	2.15	20.98	5.86	26.84	5.87	12.03	26.81
0.11	1.38	17.87	2.12	19.99	5.59	25.57	5.63	11.77	24.73
0.12	1.47	16.96	2.09	19.05	5.33	24.38	5.39	11.52	22.81
0.13	1.56	16.10	2.07	18.17	5.09	23.26	5.16	11.27	21.04
0.14	1.65	15.29	2.05	17.34	4.86	22.20	4.93	11.02	19.39
0.15	1.75	14.53	2.03	16.56	4.64	21.20	4.71	10.78	17.88
0.16	1.84	13.81	2.01	15.82	4.43	20.25	4.50	10.55	16.47
0.17	1.93	13.13	1.99	15.12	4.24	19.36	4.30	10.31	15.18
0.18	2.02	12.49	1.98	14.47	4.05	18.51	4.11	10.09	13.99
0.19	2.12	11.88	1.96	13.84	3.87	17.72	3.92	9.86	12.88
0.20	2.21	11.31	1.95	13.26	3.70	16.96	3.74	9.64	11.87
0.21	2.31	10.77	1.94	12.71	3.54	16.24	3.57	9.43	10.93
0.22	2.40	10.26	1.93	12.18	3.38	15.57	3.40	9.22	10.07
0.23	2.49	9.77	1.92	11.69	3.24	14.93	3.27	9.01	9.27
0.24	2.59	9.32	1.91	11.23	3.10	14.32	3.20	8.81	8.54
0.25	2.68	8.88	1.90	10.79	2.96	13.75	3.14	8.61	7.87

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.78	8.47	1.90	10.37	2.83	13.20	3.07	8.41	7.25
0.27	2.87	8.08	1.89	9.98	2.71	12.68	3.01	8.22	6.68
0.28	2.96	7.72	1.89	9.60	2.59	12.19	3.00	8.04	6.15
0.29	3.06	7.37	1.88	9.25	2.48	11.73	3.00	7.85	5.67
0.30	3.15	7.04	1.88	8.92	2.37	11.29	3.00	7.68	5.22
0.31	3.25	6.73	1.88	8.60	2.26	10.87	3.00	7.50	4.81
0.32	3.35	6.43	1.87	8.30	2.16	10.47	3.00	7.33	4.43
0.33	3.44	6.15	1.87	8.02	2.07	10.09	3.00	7.17	4.09
0.34	3.54	5.88	1.87	7.75	1.97	9.73	3.00	7.00	3.77
0.35	3.63	5.63	1.87	7.50	1.88	9.38	3.00	6.84	3.47
0.36	3.73	5.38	1.87	7.26	1.79	9.05	3.00	6.69	3.20
0.37	3.82	5.16	1.87	7.03	1.71	8.74	3.00	6.54	2.95
0.38	3.92	4.94	1.88	6.81	1.63	8.44	3.00	6.39	2.72
0.39	4.02	4.73	1.88	6.61	1.55	8.16	3.00	6.24	2.51
0.40	4.11	4.53	1.88	6.41	1.47	7.88	3.00	6.10	2.32
0.41	4.21	4.34	1.88	6.23	1.40	7.63	3.00	5.96	2.14
0.42	4.31	4.17	1.89	6.05	1.33	7.38	3.00	5.83	1.98
0.43	4.40	4.00	1.89	5.89	1.26	7.15	3.00	5.70	1.82
0.44	4.50	3.83	1.89	5.73	1.20	6.92	3.00	5.57	1.68
0.45	4.60	3.68	1.90	5.58	1.14	6.71	3.00	5.44	1.56
0.46	4.69	3.53	1.90	5.43	1.08	6.51	3.00	5.32	1.44
0.47	4.79	3.39	1.91	5.30	1.03	6.32	3.00	5.20	1.33
0.48	4.89	3.26	1.91	5.17	0.97	6.14	3.00	5.08	1.23
0.49	4.99	3.13	1.92	5.05	0.93	5.97	3.00	4.97	1.13
0.50	5.09	3.01	1.92	4.93	0.88	5.81	3.00	4.86	1.05
0.51	5.18	2.89	1.93	4.82	0.84	5.66	3.00	4.75	0.97

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	5.28	2.78	1.94	4.71	0.80	5.51	3.00	4.64	0.90
0.53	5.38	2.67	1.94	4.61	0.76	5.37	3.00	4.54	0.83
0.54	5.48	2.57	1.95	4.52	0.72	5.24	3.00	4.44	0.77
0.55	5.58	2.47	1.96	4.43	0.69	5.11	3.00	4.34	0.71
0.56	5.68	2.38	1.96	4.34	0.66	4.99	3.00	4.24	0.66
0.57	5.77	2.29	1.97	4.26	0.62	4.88	3.00	4.15	0.61
0.58	5.87	2.20	1.98	4.18	0.59	4.77	3.00	4.06	0.56
0.59	5.97	2.12	1.98	4.10	0.57	4.67	3.00	3.97	0.52
0.60	6.07	2.04	1.99	4.03	0.54	4.57	3.00	3.88	0.48
0.61	6.17	1.96	2.00	3.96	0.52	4.48	3.00	3.80	0.45
0.62	6.27	1.89	2.00	3.90	0.49	4.39	3.00	3.71	0.41
0.63	6.37	1.82	2.01	3.83	0.47	4.30	3.00	3.63	0.38
0.64	6.47	1.76	2.02	3.77	0.45	4.22	3.00	3.55	0.36
0.65	6.57	1.69	2.03	3.72	0.43	4.15	3.00	3.47	0.34
0.66	6.67	1.63	2.03	3.66	0.41	4.07	3.00	3.40	0.32
0.67	6.77	1.57	2.04	3.61	0.39	4.00	3.00	3.32	0.30
0.68	6.87	1.52	2.05	3.56	0.37	3.94	3.00	3.25	0.28
0.69	6.97	1.46	2.05	3.52	0.36	3.87	3.00	3.18	0.27
0.70	7.07	1.41	2.06	3.47	0.34	3.81	3.00	3.11	0.25
0.71	7.17	1.36	2.07	3.43	0.33	3.76	3.00	3.05	0.24
0.72	7.28	1.31	2.08	3.39	0.31	3.70	3.00	2.98	0.22
0.73	7.38	1.27	2.08	3.35	0.30	3.65	3.00	2.92	0.21
0.74	7.48	1.22	2.09	3.31	0.29	3.60	3.00	2.86	0.20
0.75	7.58	1.18	2.10	3.28	0.27	3.55	3.00	2.79	0.19
0.76	7.68	1.14	2.11	3.24	0.26	3.51	3.00	2.73	0.18
0.77	7.78	1.10	2.11	3.21	0.25	3.46	3.00	2.68	0.17

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

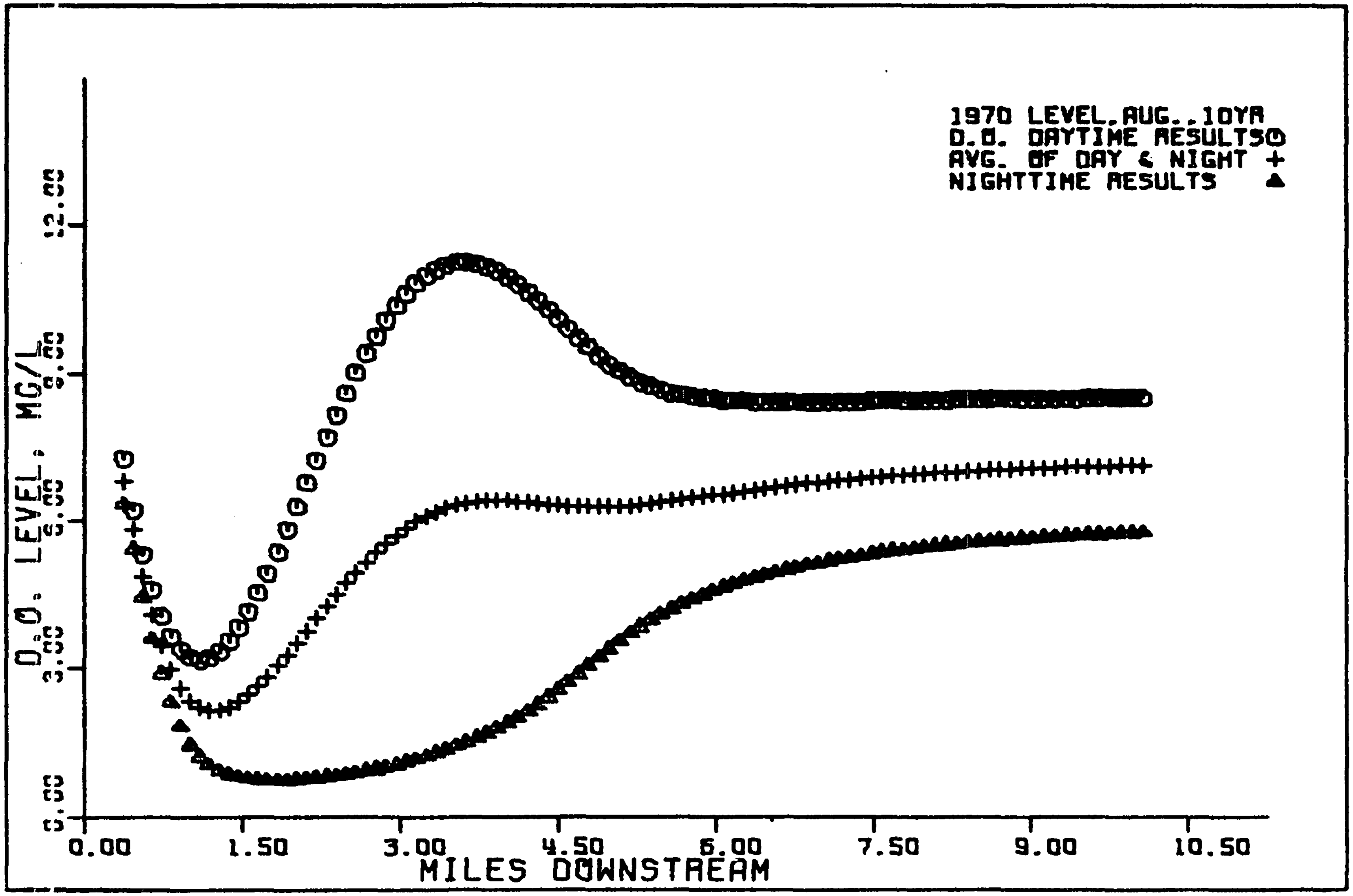
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	7.89	1.06	2.12	3.18	0.24	3.42	3.00	2.62	0.16
0.79	7.99	1.02	2.13	3.15	0.23	3.38	3.00	2.56	0.16
0.80	8.09	0.99	2.14	3.12	0.22	3.34	3.00	2.51	0.15
0.81	8.19	0.95	2.14	3.10	0.21	3.31	3.00	2.46	0.14
0.82	8.29	0.92	2.15	3.07	0.20	3.27	3.00	2.41	0.14
0.83	8.40	0.89	2.16	3.05	0.20	3.24	3.00	2.36	0.13
0.84	8.50	0.86	2.16	3.02	0.19	3.21	3.00	2.31	0.13
0.85	8.60	0.83	2.17	3.00	0.18	3.18	3.00	2.26	0.12
0.86	8.71	0.80	2.18	2.98	0.17	3.15	3.00	2.21	0.12
0.87	8.81	0.78	2.18	2.96	0.17	3.13	3.00	2.17	0.11
0.88	8.91	0.75	2.19	2.94	0.16	3.10	3.00	2.12	0.11
0.89	9.02	0.72	2.20	2.92	0.15	3.08	3.00	2.08	0.10
0.90	9.12	0.70	2.20	2.90	0.15	3.05	3.00	2.03	0.10
0.91	9.22	0.68	2.21	2.89	0.14	3.03	3.00	1.99	0.10
0.92	9.33	0.65	2.22	2.87	0.14	3.01	3.00	1.95	0.10
0.93	9.43	0.63	2.22	2.86	0.13	2.99	3.00	1.91	0.10
0.94	9.54	0.61	2.23	2.84	0.13	2.97	3.00	1.87	0.10
0.95	9.64	0.59	2.24	2.83	0.12	2.95	3.00	1.83	0.10
0.96	9.74	0.57	2.24	2.81	0.12	2.93	3.00	1.80	0.10
0.97	9.85	0.55	2.25	2.80	0.12	2.92	3.00	1.76	0.10
0.98	9.95	0.53	2.25	2.79	0.11	2.90	3.00	1.73	0.10
0.99	10.06	0.52	2.26	2.78	0.11	2.88	3.00	1.69	0.10

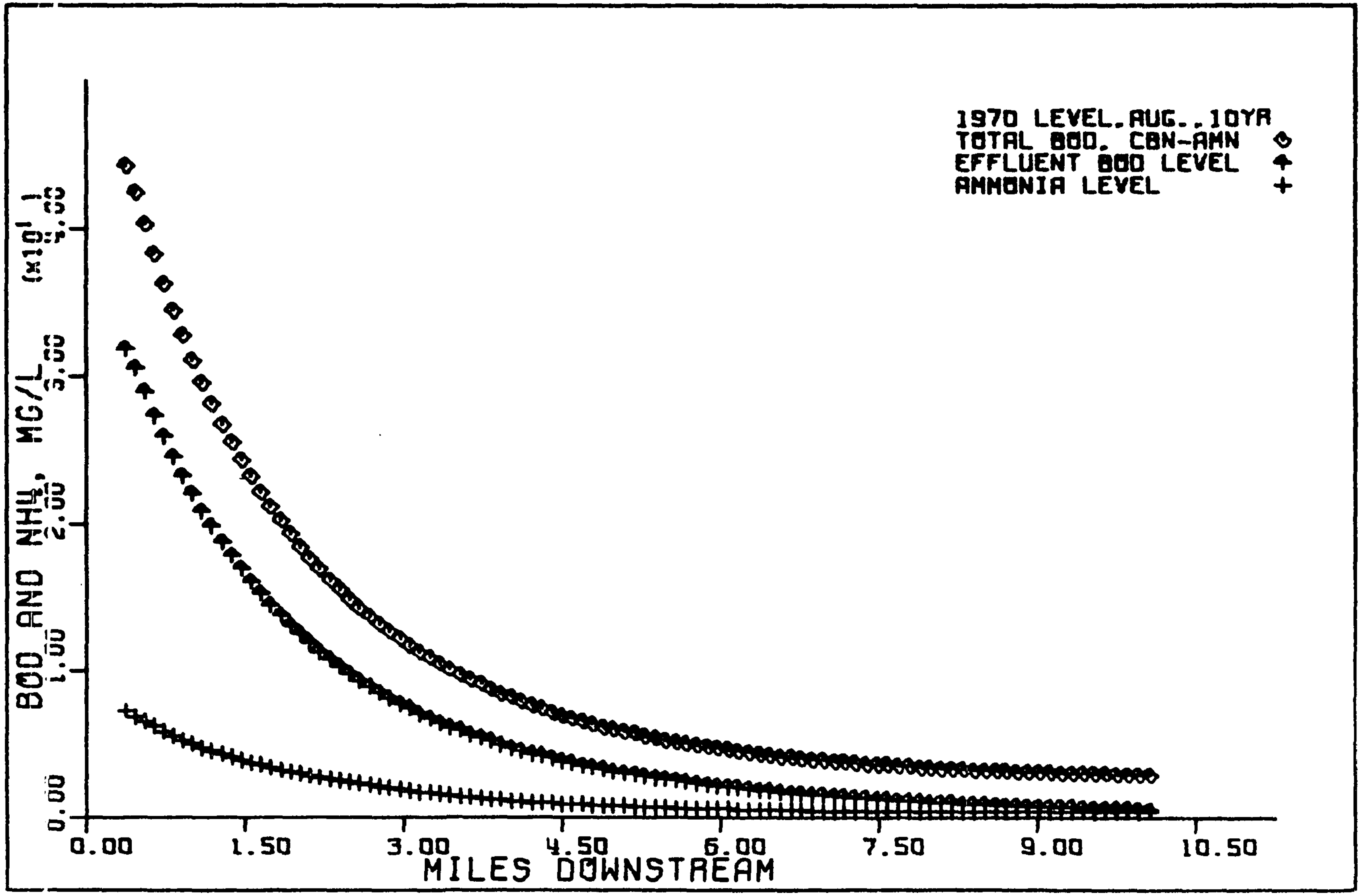
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	7.27	0.37	0.0	6.33	0.37	0.0
MINIMUM DO, MG/L	3.16	1.10	0.08	0.73	1.84	0.16
FINAL DO, MG/L	8.47	8.09	0.80	5.49	8.09	0.80
DO DEFICIT						
INITIAL, MG/L	0.62	0.37	0.0	2.11	0.37	0.0
FINAL, MG/L	-1.40	8.09	0.80	2.79	8.09	0.80
RIVER DISCHARGE						
INITIAL, CFS	12.04	0.37	0.0	12.04	0.37	0.0
FINAL, CFS	16.68	8.09	0.80	16.68	8.09	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	77.47	0.37	0.0	71.25	0.37	0.0
FINAL, DEG F	87.89	8.09	0.80	72.98	8.09	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	31.94	0.37	0.0	31.94	0.37	0.0
FINAL BOD, MG/L	0.62	8.09	0.80	1.36	8.09	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.07	0.37	0.0	0.07	0.37	0.0
FINAL BOD IN RIVER	1.89	8.09	0.80	2.38	8.09	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	9.83	0.37	0.0	9.83	0.37	0.0
FINAL BOD, MG/L	0.04	8.09	0.80	0.40	8.09	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	43.56	0.37	0.0	45.02	0.37	0.0
FINAL VALUE, MG/L	2.55	8.09	0.80	4.14	8.09	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	7.18	0.37	0.0	7.18	0.37	0.0
FINAL VALUE, MG/L	0.40	8.09	0.80	0.40	8.09	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	8.26	0.37	0.0	8.26	0.37	0.0
FINAL VALUE, MG/L	3.00	8.09	0.80	3.00	8.09	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	14.79	0.37	0.0	14.79	0.37	0.0
FINAL VALUE, MG/L	1.50	8.09	0.80	3.52	8.09	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	58.52	0.37	0.0	58.52	0.37	0.0
FINAL PERCENT	0.10	8.09	0.80	0.20	8.09	0.80


1970 LEVEL.AUG..10YR
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
MILES DOWNSTREAM
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50


1970 LEVEL. AUG.. 10YR
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10¹)
0.00
1.00
2.00
3.00
4.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM

G. Computer Results for 1970 Status Study, September, 10 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
4.55	65.00	75.00	0.0	40.00	0.080	0.0	15.00	10.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
83.00	68.00	125.00	70.00	2.50	0.140	0.0	0.40	3.00	0.40	0.10	60.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
2.50	0.30	110.00	55.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
83.00	68.00	2.500	0.0	0.0	3.000	0.100	0.40	1.20	1.60	2.50	2.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 60.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 3.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 7.04 CFS, RIVER Q = 2.50 CFS, TOTAL Q = 9.54 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 1.20 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	83.0	68.0		2.5	9.31	6.13		0.40
0.0	0.37	69.7	65.8	67.8	9.5	7.45	6.62	7.04	11.18
0.01	0.45	70.5	65.9	68.2	9.6	6.34	5.28	5.81	10.77
0.02	0.54	71.2	66.0	68.6	9.6	5.36	3.85	4.61	10.36
0.03	0.62	71.8	66.1	69.0	9.6	4.53	2.63	3.58	9.97
0.04	0.70	72.4	66.2	69.3	9.6	3.84	1.57	2.71	9.59
0.05	0.79	73.0	66.3	69.7	9.7	3.29	0.77	2.03	9.23
0.06	0.87	73.6	66.4	70.0	9.7	2.86	0.26	1.56	8.93
0.07	0.95	74.1	66.5	70.3	9.7	2.55	0.0	1.27	8.64
0.08	1.04	74.6	66.6	70.6	9.7	2.35	0.0	1.17	8.36
0.09	1.12	75.1	66.7	70.9	9.8	2.25	0.0	1.12	8.09
0.10	1.20	75.5	66.8	71.1	9.8	2.24	0.0	1.12	7.83
0.11	1.29	75.9	66.8	71.4	9.8	2.31	0.0	1.16	7.57
0.12	1.37	76.3	66.9	71.6	9.8	2.46	0.0	1.23	7.32
0.13	1.46	76.7	67.0	71.8	9.9	2.68	0.0	1.34	7.08
0.14	1.54	77.1	67.0	72.0	9.9	2.96	0.0	1.48	6.84
0.15	1.62	77.4	67.1	72.2	9.9	3.30	0.0	1.65	6.62
0.16	1.71	77.7	67.1	72.4	9.9	3.67	0.0	1.84	6.40
0.17	1.79	78.0	67.2	72.6	10.0	4.09	0.0	2.05	6.18
0.18	1.88	78.3	67.2	72.7	10.0	4.55	0.0	2.27	5.98
0.19	1.96	78.5	67.3	72.9	10.0	5.02	0.0	2.51	5.78
0.20	2.05	78.8	67.3	73.0	10.0	5.52	0.0	2.76	5.59
0.21	2.13	79.0	67.3	73.2	10.1	6.03	0.0	3.02	5.41
0.22	2.22	79.3	67.4	73.3	10.1	6.55	0.0	3.27	5.23
0.23	2.30	79.5	67.4	73.4	10.1	7.07	0.0	3.54	5.06
0.24	2.39	79.7	67.4	73.6	10.1	7.59	0.0	3.80	4.89
0.25	2.47	79.8	67.5	73.7	10.2	8.10	0.0	4.05	4.74

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.56	80.0	67.5	73.8	10.2	8.60	0.0	4.30	4.58
0.27	2.64	80.2	67.5	73.9	10.2	9.09	0.0	4.54	4.44
0.28	2.73	80.3	67.6	74.0	10.3	9.55	0.0	4.78	4.30
0.29	2.81	80.5	67.6	74.0	10.3	9.99	0.0	5.00	4.16
0.30	2.90	80.6	67.6	74.1	10.3	10.41	0.0	5.20	4.03
0.31	2.98	80.8	67.6	74.2	10.3	10.79	0.0	5.40	3.91
0.32	3.07	80.9	67.6	74.3	10.4	11.15	0.0	5.57	3.79
0.33	3.15	81.0	67.7	74.3	10.4	11.47	0.0	5.73	3.67
0.34	3.24	81.1	67.7	74.4	10.4	11.75	0.0	5.88	3.56
0.35	3.33	81.2	67.7	74.5	10.4	12.00	0.0	6.00	3.46
0.36	3.41	81.3	67.7	74.5	10.5	12.21	0.0	6.11	3.36
0.37	3.50	81.4	67.7	74.6	10.5	12.39	0.0	6.19	3.26
0.38	3.58	81.5	67.8	74.6	10.5	12.53	0.0	6.26	3.17
0.39	3.67	81.6	67.8	74.7	10.5	12.63	0.0	6.31	3.07
0.40	3.76	81.7	67.8	74.7	10.6	12.69	0.0	6.35	2.99
0.41	3.84	81.7	67.8	74.8	10.6	12.72	0.0	6.36	2.90
0.42	3.93	81.8	67.3	74.8	10.6	12.72	0.0	6.36	2.82
0.43	4.02	81.9	67.8	74.8	10.6	12.68	0.0	6.34	2.75
0.44	4.10	81.9	67.8	74.9	10.7	12.62	0.0	6.31	2.67
0.45	4.19	82.0	67.8	74.9	10.7	12.52	0.0	6.26	2.60
0.46	4.27	82.1	67.8	74.9	10.7	12.41	0.0	6.20	2.53
0.47	4.36	82.1	67.9	75.0	10.7	12.26	0.01	6.14	2.46
0.48	4.45	82.2	67.9	75.0	10.8	12.10	0.03	6.07	2.40
0.49	4.54	82.2	67.9	75.0	10.8	11.93	0.08	6.00	2.34
0.50	4.62	82.3	67.9	75.1	10.8	11.74	0.13	5.93	2.28
0.51	4.71	82.3	67.9	75.1	10.8	11.53	0.21	5.87	2.22

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.80	82.3	67.9	75.1	10.9	11.33	0.29	5.81	2.16
0.53	4.88	82.4	67.9	75.1	10.9	11.11	0.39	5.75	2.11
0.54	4.97	82.4	67.9	75.2	10.9	10.90	0.49	5.70	2.06
0.55	5.06	82.4	67.9	75.2	10.9	10.69	0.60	5.65	2.01
0.56	5.15	82.5	67.9	75.2	11.0	10.49	0.72	5.61	1.96
0.57	5.23	82.5	67.9	75.2	11.0	10.30	0.83	5.57	1.92
0.58	5.32	82.5	67.9	75.2	11.0	10.12	0.95	5.53	1.88
0.59	5.41	82.6	67.9	75.2	11.1	9.95	1.05	5.50	1.84
0.60	5.50	82.6	67.9	75.3	11.1	9.81	1.15	5.48	1.79
0.61	5.58	82.6	67.9	75.3	11.1	9.68	1.25	5.46	1.75
0.62	5.67	82.6	67.9	75.3	11.1	9.57	1.33	5.45	1.71
0.63	5.76	82.6	67.9	75.3	11.2	9.48	1.40	5.44	1.66
0.64	5.85	82.7	67.9	75.3	11.2	9.41	1.47	5.44	1.62
0.65	5.94	82.7	67.9	75.3	11.2	9.34	1.53	5.44	1.58
0.66	6.02	82.7	68.0	75.3	11.2	9.29	1.59	5.44	1.53
0.67	6.11	82.7	68.0	75.3	11.3	9.25	1.65	5.45	1.49
0.68	6.20	82.7	68.0	75.3	11.3	9.22	1.70	5.46	1.45
0.69	6.29	82.7	68.0	75.4	11.3	9.20	1.75	5.47	1.41
0.70	6.38	82.8	68.0	75.4	11.3	9.18	1.80	5.49	1.37
0.71	6.47	82.9	68.0	75.4	11.4	9.16	1.85	5.50	1.33
0.72	6.56	82.8	68.0	75.4	11.4	9.15	1.89	5.52	1.29
0.73	6.64	82.8	68.0	75.4	11.4	9.14	1.94	5.54	1.25
0.74	6.73	82.8	68.0	75.4	11.5	9.14	1.99	5.56	1.21
0.75	6.82	82.8	68.0	75.4	11.5	9.13	2.03	5.58	1.18
0.76	6.91	82.8	68.0	75.4	11.5	9.13	2.08	5.61	1.14
0.77	7.00	82.8	68.0	75.4	11.5	9.13	2.13	5.63	1.11

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	7.09	82.9	68.0	75.4	11.6	9.14	2.18	5.66	1.08
0.79	7.18	82.9	68.0	75.4	11.6	9.14	2.23	5.68	1.04
0.80	7.27	82.9	68.0	75.4	11.6	9.14	2.28	5.71	1.01
0.81	7.36	82.9	68.0	75.4	11.6	9.15	2.33	5.74	0.98
0.82	7.45	82.9	68.0	75.4	11.7	9.15	2.38	5.77	0.96
0.83	7.54	82.9	68.0	75.4	11.7	9.16	2.43	5.79	0.93
0.84	7.63	82.9	68.0	75.4	11.7	9.16	2.48	5.82	0.90
0.85	7.72	82.9	68.0	75.4	11.7	9.17	2.53	5.85	0.88
0.86	7.81	82.9	68.0	75.4	11.8	9.17	2.58	5.87	0.85
0.87	7.90	82.9	68.0	75.4	11.8	9.18	2.63	5.90	0.83
0.88	7.99	82.9	68.0	75.5	11.8	9.18	2.67	5.93	0.81
0.89	8.08	82.9	68.0	75.5	11.9	9.19	2.72	5.95	0.78
0.90	8.17	82.9	68.0	75.5	11.9	9.19	2.76	5.98	0.76
0.91	8.26	82.9	68.0	75.5	11.9	9.20	2.81	6.00	0.74
0.92	8.35	82.9	68.0	75.5	11.9	9.20	2.85	6.03	0.72
0.93	8.44	82.9	68.0	75.5	12.0	9.21	2.89	6.05	0.70
0.94	8.53	82.9	68.0	75.5	12.0	9.21	2.93	6.07	0.69
0.95	8.62	82.9	68.0	75.5	12.0	9.22	2.97	6.09	0.67
0.96	8.71	82.9	68.0	75.5	12.0	9.22	3.01	6.11	0.65
0.97	8.80	82.9	68.0	75.5	12.1	9.23	3.04	6.13	0.64
0.98	8.89	83.0	68.0	75.5	12.1	9.23	3.08	6.15	0.62
0.99	8.98	83.0	68.0	75.5	12.1	9.23	3.11	6.17	0.61

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.50	2.33	4.83	0.55	5.37	3.00	0.40	0.10
0.0	0.37	39.92	3.22	43.14	15.29	58.42	8.17	18.56	73.83
0.01	0.45	38.48	3.21	41.69	14.73	56.42	8.06	18.30	69.43
0.02	0.54	36.68	3.16	39.85	14.18	54.02	7.96	18.04	65.24
0.03	0.62	34.96	3.12	38.08	13.64	51.72	7.85	17.78	61.26
0.04	0.70	33.32	3.08	36.40	13.11	49.51	7.73	17.52	57.49
0.05	0.79	31.76	3.04	34.80	12.63	47.43	7.58	17.26	53.91
0.06	0.87	30.28	3.00	33.28	12.21	45.49	7.39	17.00	50.53
0.07	0.95	28.94	2.97	31.91	11.82	43.73	7.21	16.76	47.50
0.08	1.04	27.74	2.96	30.70	11.44	42.14	7.04	16.52	44.82
0.09	1.12	26.59	2.94	29.53	11.07	40.61	6.87	16.29	42.27
0.10	1.20	25.49	2.93	28.42	10.71	39.13	6.70	16.06	39.85
0.11	1.29	24.45	2.92	27.36	10.36	37.72	6.53	15.82	37.57
0.12	1.37	23.45	2.90	26.35	10.02	36.37	6.37	15.59	35.40
0.13	1.46	22.49	2.89	25.38	9.68	35.07	6.20	15.37	33.36
0.14	1.54	21.58	2.88	24.46	9.36	33.83	6.04	15.14	31.43
0.15	1.62	20.71	2.88	23.58	9.05	32.63	5.87	14.91	29.61
0.16	1.71	19.88	2.87	22.74	8.75	31.49	5.71	14.69	27.90
0.17	1.79	19.08	2.86	21.94	8.46	30.40	5.55	14.47	26.28
0.18	1.88	18.32	2.86	21.18	8.18	29.36	5.39	14.25	24.76
0.19	1.96	17.60	2.85	20.45	7.91	28.36	5.24	14.03	23.32
0.20	2.05	16.91	2.85	19.76	7.65	27.40	5.08	13.82	21.97
0.21	2.13	16.25	2.84	19.10	7.39	26.49	4.93	13.60	20.70
0.22	2.22	15.62	2.84	18.46	7.15	25.62	4.78	13.39	19.51
0.23	2.30	15.02	2.84	17.86	6.92	24.78	4.63	13.19	18.38
0.24	2.39	14.45	2.84	17.29	6.69	23.98	4.49	12.98	17.33
0.25	2.47	13.90	2.84	16.74	6.48	23.22	4.35	12.78	16.33

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.56	13.38	2.84	16.22	6.27	22.49	4.21	12.58	15.40
0.27	2.64	12.88	2.84	15.72	6.07	21.79	4.08	12.38	14.52
0.28	2.73	12.40	2.84	15.24	5.88	21.12	3.95	12.19	13.70
0.29	2.81	11.94	2.84	14.79	5.69	20.48	3.82	11.99	12.92
0.30	2.90	11.50	2.85	14.35	5.52	19.87	3.69	11.80	12.19
0.31	2.98	11.09	2.85	13.94	5.35	19.28	3.57	11.62	11.51
0.32	3.07	10.68	2.86	13.54	5.18	18.72	3.46	11.43	10.86
0.33	3.15	10.30	2.86	13.16	5.03	18.19	3.34	11.25	10.26
0.34	3.24	9.93	2.87	12.80	4.88	17.68	3.26	11.07	9.69
0.35	3.33	9.58	2.87	12.46	4.73	17.19	3.21	10.90	9.15
0.36	3.41	9.25	2.88	12.13	4.59	16.72	3.17	10.73	8.65
0.37	3.50	8.92	2.89	11.81	4.46	16.27	3.12	10.56	8.18
0.38	3.58	8.61	2.89	11.51	4.33	15.84	3.08	10.39	7.73
0.39	3.67	8.32	2.90	11.22	4.21	15.43	3.04	10.22	7.31
0.40	3.76	8.03	2.91	10.94	4.09	15.03	3.00	10.06	6.92
0.41	3.84	7.76	2.92	10.68	3.97	14.65	3.00	9.90	6.54
0.42	3.93	7.50	2.93	10.43	3.86	14.29	3.00	9.75	6.19
0.43	4.02	7.25	2.94	10.19	3.76	13.94	3.00	9.59	5.86
0.44	4.10	7.01	2.95	9.95	3.66	13.61	3.00	9.44	5.55
0.45	4.19	6.77	2.96	9.73	3.56	13.29	3.00	9.29	5.26
0.46	4.27	6.55	2.97	9.52	3.46	12.98	3.00	9.14	4.98
0.47	4.36	6.34	2.98	9.31	3.37	12.69	3.00	9.00	4.72
0.48	4.45	6.13	2.99	9.12	3.28	12.40	3.00	8.86	4.47
0.49	4.54	5.93	3.00	8.93	3.20	12.13	3.00	8.72	4.24
0.50	4.62	5.73	3.01	8.74	3.12	11.86	3.00	8.58	4.01
0.51	4.71	5.54	3.02	8.56	3.04	11.59	3.00	8.44	3.79

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.80	5.35	3.02	8.37	2.96	11.33	3.00	8.30	3.58
0.53	4.88	5.16	3.03	8.19	2.89	11.08	3.00	8.16	3.37
0.54	4.97	4.98	3.03	8.00	2.82	10.82	3.00	8.02	3.16
0.55	5.06	4.79	3.03	7.82	2.75	10.57	3.00	7.89	2.96
0.56	5.15	4.61	3.03	7.64	2.68	10.32	3.00	7.75	2.78
0.57	5.23	4.45	3.03	7.47	2.61	10.08	3.00	7.61	2.60
0.58	5.32	4.28	3.03	7.31	2.54	9.85	3.00	7.48	2.44
0.59	5.41	4.13	3.03	7.16	2.47	9.62	3.00	7.35	2.28
0.60	5.50	3.98	3.03	7.01	2.39	9.40	3.00	7.23	2.14
0.61	5.58	3.83	3.03	6.87	2.32	9.19	3.00	7.10	2.01
0.62	5.67	3.70	3.04	6.73	2.25	8.98	3.00	6.98	1.88
0.63	5.76	3.56	3.04	6.61	2.18	8.79	3.00	6.86	1.76
0.64	5.85	3.44	3.05	6.48	2.11	8.59	3.00	6.74	1.65
0.65	5.94	3.32	3.05	6.37	2.04	8.41	3.00	6.62	1.55
0.66	6.02	3.20	3.06	6.26	1.97	8.23	3.00	6.51	1.45
0.67	6.11	3.09	3.06	6.15	1.90	8.05	3.00	6.40	1.36
0.68	6.20	2.98	3.07	6.05	1.84	7.89	3.00	6.29	1.28
0.69	6.29	2.88	3.08	5.95	1.77	7.73	3.00	6.18	1.20
0.70	6.38	2.78	3.08	5.86	1.71	7.57	3.00	6.08	1.12
0.71	6.47	2.68	3.09	5.77	1.65	7.42	3.00	5.97	1.05
0.72	6.56	2.59	3.10	5.69	1.59	7.28	3.00	5.87	0.99
0.73	6.64	2.50	3.11	5.61	1.53	7.14	3.00	5.77	0.93
0.74	6.73	2.42	3.11	5.53	1.47	7.01	3.00	5.67	0.87
0.75	6.82	2.33	3.12	5.46	1.42	6.88	3.00	5.58	0.82
0.76	6.91	2.26	3.13	5.39	1.37	6.75	3.00	5.48	0.77
0.77	7.00	2.18	3.14	5.32	1.31	6.64	3.00	5.39	0.72

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

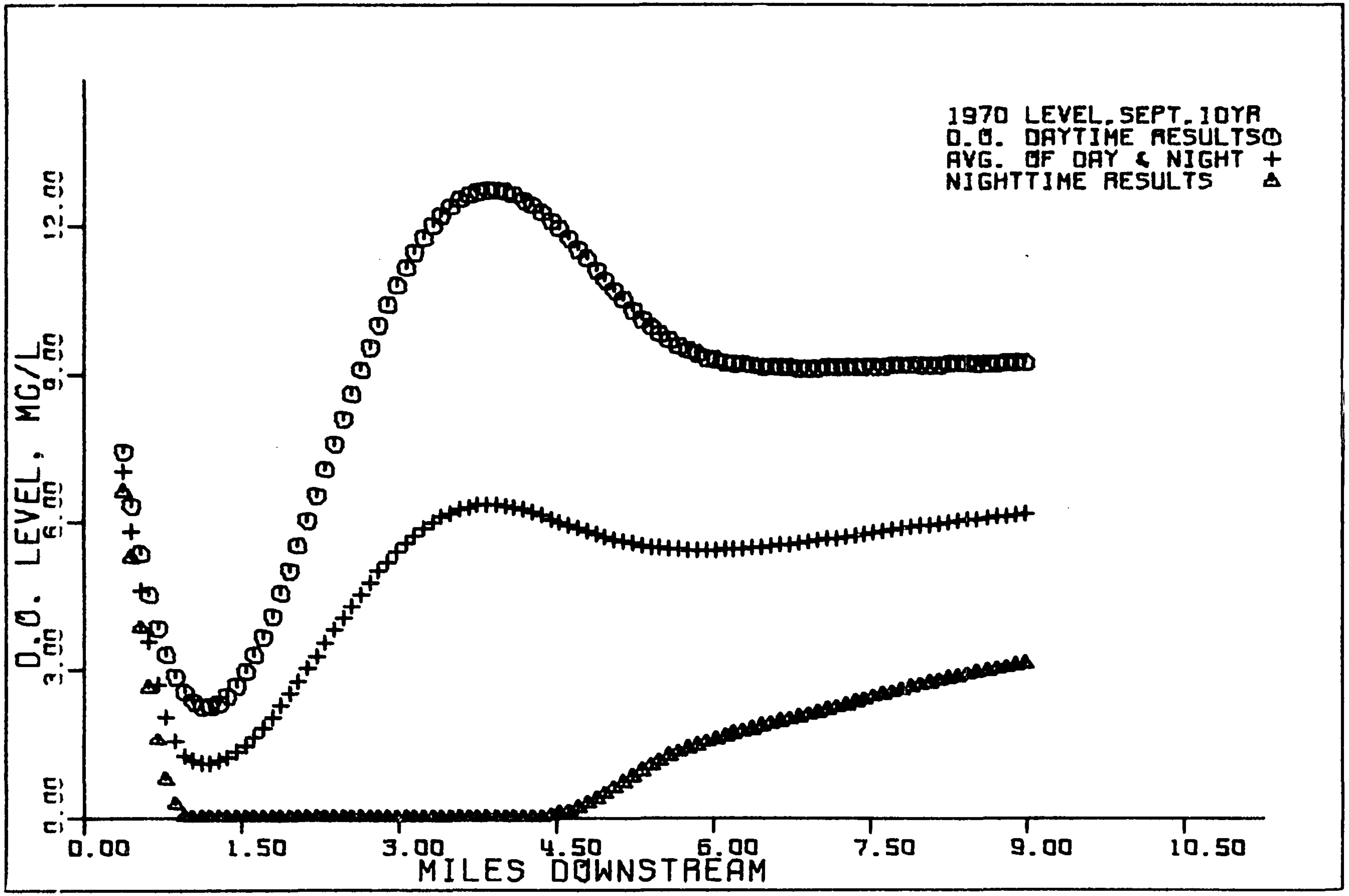
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	7.09	2.11	3.15	5.26	1.27	6.52	3.00	5.30	0.68
0.79	7.18	2.04	3.16	5.20	1.22	6.42	3.00	5.21	0.64
0.80	7.27	1.97	3.17	5.14	1.17	6.31	3.00	5.12	0.61
0.81	7.36	1.90	3.18	5.08	1.13	6.21	3.00	5.04	0.57
0.82	7.45	1.84	3.19	5.03	1.09	6.12	3.00	4.95	0.54
0.83	7.54	1.78	3.20	4.98	1.05	6.03	3.00	4.87	0.51
0.84	7.63	1.72	3.21	4.93	1.01	5.94	3.00	4.79	0.48
0.85	7.72	1.67	3.22	4.89	0.97	5.86	3.00	4.71	0.46
0.86	7.81	1.61	3.23	4.84	0.94	5.78	3.00	4.63	0.43
0.87	7.90	1.56	3.24	4.80	0.90	5.70	3.00	4.55	0.41
0.88	7.99	1.51	3.25	4.76	0.87	5.63	3.00	4.48	0.39
0.89	8.08	1.46	3.27	4.73	0.84	5.56	3.00	4.40	0.37
0.90	8.17	1.41	3.28	4.69	0.81	5.50	3.00	4.33	0.35
0.91	8.26	1.37	3.29	4.66	0.78	5.43	3.00	4.26	0.33
0.92	8.35	1.32	3.30	4.62	0.75	5.37	3.00	4.19	0.32
0.93	8.44	1.28	3.31	4.59	0.72	5.31	3.00	4.12	0.30
0.94	8.53	1.24	3.32	4.56	0.69	5.26	3.00	4.05	0.29
0.95	8.62	1.20	3.33	4.54	0.67	5.20	3.00	3.99	0.27
0.96	8.71	1.16	3.34	4.51	0.65	5.15	3.00	3.92	0.26
0.97	8.80	1.13	3.36	4.48	0.62	5.11	3.00	3.86	0.25
0.98	8.89	1.09	3.37	4.46	0.60	5.06	3.00	3.79	0.23
0.99	8.98	1.06	3.38	4.44	0.58	5.01	3.00	3.73	0.22

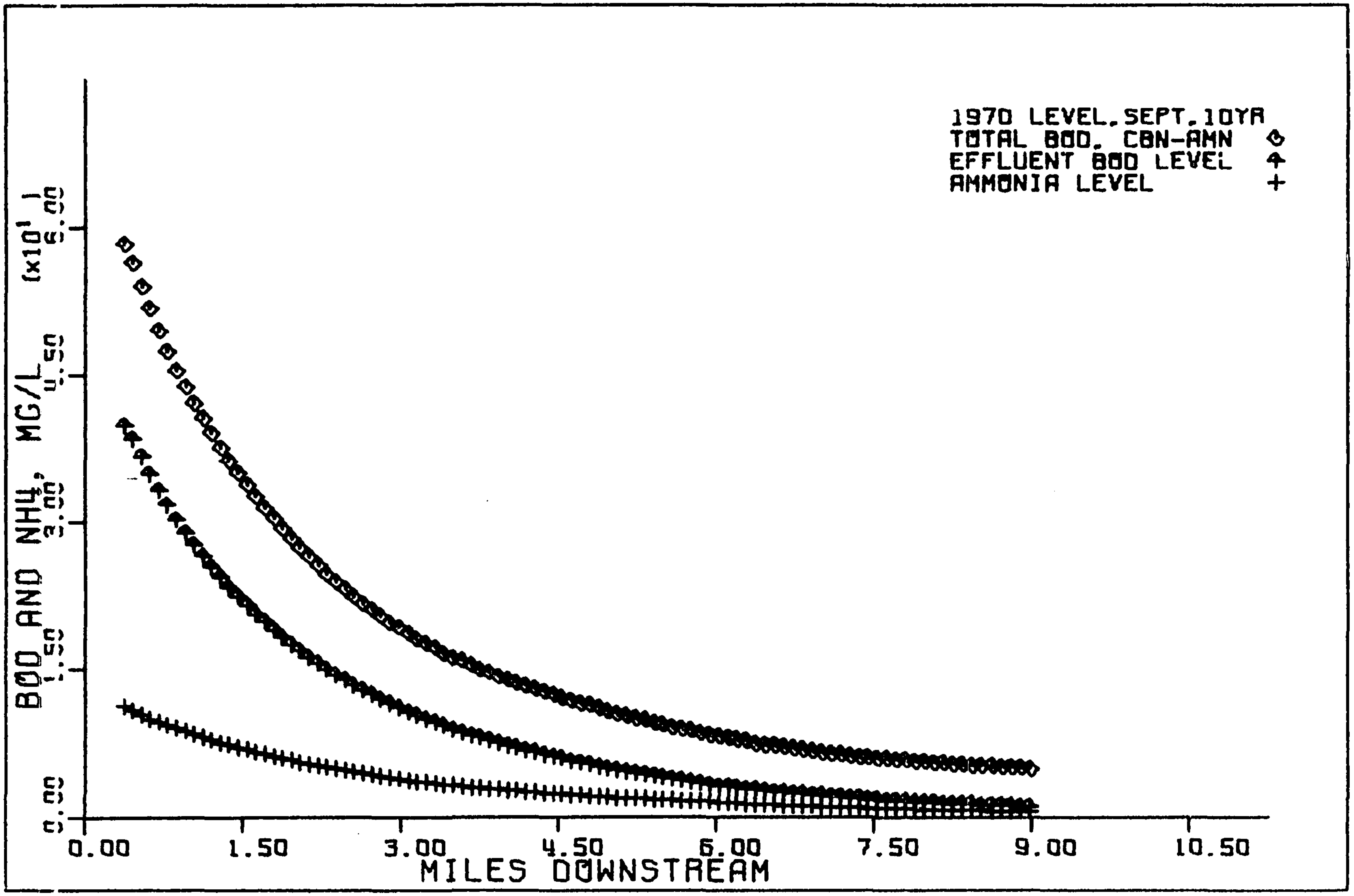
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	7.45	0.37	0.0	6.62	0.37	0.0
MINIMUM DO, MG/L	2.24	1.20	0.10	0.0	0.95	0.07
FINAL DO, MG/L	9.14	7.27	0.80	2.28	7.27	0.80
DO DEFICIT						
INITIAL, MG/L	1.13	0.37	0.0	2.36	0.37	0.0
FINAL, MG/L	-1.69	7.27	0.80	6.47	7.27	0.80
RIVER DISCHARGE						
INITIAL, CFS	9.54	0.37	0.0	9.54	0.37	0.0
FINAL, CFS	11.61	7.27	0.80	11.61	7.27	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	69.72	0.37	0.0	65.79	0.37	0.0
FINAL, DEG F	82.87	7.27	0.80	67.98	7.27	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	39.92	0.37	0.0	39.92	0.37	0.0
FINAL BOD, MG/L	1.04	7.27	0.80	2.89	7.27	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.10	0.37	0.0	0.10	0.37	0.0
FINAL BOD IN RIVER	2.78	7.27	0.80	3.56	7.27	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	15.29	0.37	0.0	15.29	0.37	0.0
FINAL BOD, MG/L	0.12	7.27	0.80	2.22	7.27	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	57.54	0.37	0.0	59.31	0.37	0.0
FINAL VALUE, MG/L	3.95	7.27	0.80	8.68	7.27	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	11.18	0.37	0.0	11.18	0.37	0.0
FINAL VALUE, MG/L	0.40	7.27	0.80	1.63	7.27	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	8.17	0.37	0.0	8.17	0.37	0.0
FINAL VALUE, MG/L	3.00	7.27	0.80	3.00	7.27	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	18.56	0.37	0.0	18.56	0.37	0.0
FINAL VALUE, MG/L	3.20	7.27	0.80	7.04	7.27	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	73.83	0.37	0.0	73.83	0.37	0.0
FINAL PERCENT	0.10	7.27	0.80	1.11	7.27	0.80


1970 LEVEL, SEPT. 10YR
D.O. DAYTIME RESULTS ⊖
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM



1970 LEVEL.SEPT.10YR
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10¹)
0.00
1.50
3.00
4.50
6.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM

H. Computer Results for 1970 Status Study, October-November, 10 Yr

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
4.55	60.00	75.00	0.0	40.00	0.080	0.0	17.00	8.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
73.00	58.00	130.00	65.00	3.00	0.140	0.0	0.40	3.00	0.40	0.10	70.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
1.00	0.15	115.00	50.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
73.00	58.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	1.50	2.50	1.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDOCY	DLOCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
     SEASON : OCT-NOV

 GAMMA1 =    0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    70.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   3.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    7.04 CFS, RIVER Q =    1.00 CFS, TOTAL Q =    8.04 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   1.00 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	73.0	58.0		1.0	10.76	6.41		0.40
0.0	0.37	61.6	59.8	60.7	8.0	7.65	7.11	7.38	14.94
0.01	0.45	62.3	59.7	61.0	8.1	6.59	5.71	6.15	14.54
0.02	0.53	62.9	59.6	61.2	8.1	5.64	4.22	4.93	14.15
0.03	0.60	63.4	59.5	61.4	8.1	4.80	2.94	3.87	13.76
0.04	0.68	64.0	59.4	61.7	8.1	4.07	1.83	2.95	13.38
0.05	0.76	64.5	59.3	61.9	8.1	3.45	0.91	2.18	13.02
0.06	0.84	64.9	59.2	62.1	8.1	2.93	0.34	1.63	12.71
0.07	0.92	65.4	59.2	62.3	8.1	2.50	0.0	1.25	12.43
0.08	0.99	65.8	59.1	62.5	8.1	2.15	0.0	1.08	12.15
0.09	1.07	66.2	59.0	62.6	8.1	1.89	0.0	0.95	11.87
0.10	1.15	66.6	59.0	62.8	8.2	1.73	0.0	0.87	11.61
0.11	1.23	67.0	58.9	62.9	8.2	1.68	0.0	0.84	11.36
0.12	1.31	67.3	58.9	63.1	8.2	1.69	0.0	0.84	11.12
0.13	1.39	67.6	58.8	63.2	8.2	1.74	0.0	0.87	10.88
0.14	1.46	67.9	58.8	63.3	8.2	1.83	0.0	0.91	10.64
0.15	1.54	68.2	58.7	63.5	8.2	1.93	0.0	0.96	10.40
0.16	1.62	68.5	58.7	63.6	8.2	2.04	0.0	1.02	10.16
0.17	1.70	68.7	58.7	63.7	8.2	2.19	0.0	1.09	9.93
0.18	1.78	69.0	58.6	63.8	8.3	2.37	0.0	1.18	9.69
0.19	1.86	69.2	58.6	63.9	8.3	2.58	0.0	1.29	9.47
0.20	1.94	69.4	58.6	64.0	8.3	2.83	0.0	1.42	9.25
0.21	2.02	69.6	58.5	64.1	8.3	3.11	0.0	1.55	9.03
0.22	2.09	69.8	58.5	64.1	8.3	3.41	0.0	1.70	8.82
0.23	2.17	70.0	58.5	64.2	8.3	3.73	0.0	1.87	8.61
0.24	2.25	70.1	58.4	64.3	8.3	4.07	0.0	2.04	8.41
0.25	2.33	70.3	58.4	64.4	8.3	4.43	0.0	2.21	8.22

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	2.41	70.4	58.4	64.4	8.3	4.79	0.0	2.40	8.03
0.27	2.49	70.6	58.4	64.5	8.4	5.17	0.0	2.58	7.85
0.28	2.57	70.7	58.4	64.5	8.4	5.55	0.0	2.78	7.67
0.29	2.65	70.9	58.3	64.6	8.4	5.94	0.0	2.97	7.49
0.30	2.73	71.0	58.3	64.6	8.4	6.33	0.0	3.16	7.32
0.31	2.81	71.1	58.3	64.7	8.4	6.72	0.0	3.36	7.16
0.32	2.88	71.2	58.3	64.7	8.4	7.11	0.0	3.55	7.00
0.33	2.96	71.3	58.3	64.8	8.4	7.49	0.0	3.75	6.84
0.34	3.04	71.4	58.2	64.8	8.4	7.88	0.0	3.94	6.69
0.35	3.12	71.5	58.2	64.9	8.5	8.25	0.0	4.13	6.54
0.36	3.20	71.6	58.2	64.9	8.5	8.62	0.0	4.31	6.40
0.37	3.28	71.6	58.2	64.9	8.5	8.98	0.0	4.49	6.26
0.38	3.36	71.7	58.2	65.0	8.5	9.33	0.0	4.66	6.12
0.39	3.44	71.8	58.2	65.0	8.5	9.66	0.0	4.83	5.99
0.40	3.52	71.9	58.2	65.0	8.5	9.99	0.0	4.99	5.87
0.41	3.60	71.9	58.2	65.0	8.5	10.30	0.0	5.15	5.74
0.42	3.68	72.0	58.2	65.1	8.5	10.59	0.0	5.30	5.62
0.43	3.76	72.0	58.1	65.1	8.6	10.88	0.0	5.44	5.50
0.44	3.84	72.1	58.1	65.1	8.6	11.14	0.0	5.57	5.39
0.45	3.92	72.1	58.1	65.1	8.6	11.39	0.0	5.70	5.28
0.46	4.00	72.2	58.1	65.2	8.6	11.62	0.0	5.81	5.17
0.47	4.08	72.2	58.1	65.2	8.6	11.84	0.0	5.92	5.07
0.48	4.16	72.3	58.1	65.2	8.6	12.04	0.0	6.02	4.97
0.49	4.24	72.3	58.1	65.2	8.6	12.22	0.00	6.11	4.87
0.50	4.32	72.4	58.1	65.2	8.6	12.38	0.01	6.19	4.77
0.51	4.40	72.4	58.1	65.2	8.6	12.52	0.02	6.27	4.68

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.48	72.4	58.1	65.3	8.7	12.65	0.03	6.34	4.59
0.53	4.56	72.5	58.1	65.3	8.7	12.76	0.05	6.40	4.50
0.54	4.64	72.5	58.1	65.3	8.7	12.85	0.07	6.46	4.41
0.55	4.72	72.5	58.1	65.3	8.7	12.92	0.09	6.51	4.33
0.56	4.80	72.5	58.1	65.3	8.7	12.98	0.12	6.55	4.25
0.57	4.88	72.6	58.1	65.3	8.7	13.01	0.14	6.58	4.17
0.58	4.96	72.6	58.1	65.3	8.7	13.04	0.17	6.60	4.09
0.59	5.04	72.6	58.1	65.3	8.7	13.04	0.20	6.62	4.02
0.60	5.12	72.6	58.1	65.3	8.8	13.03	0.24	6.63	3.94
0.61	5.20	72.7	58.1	65.4	8.8	13.01	0.27	6.64	3.87
0.62	5.28	72.7	58.0	65.4	8.8	12.97	0.30	6.64	3.80
0.63	5.36	72.7	58.0	65.4	8.8	12.92	0.34	6.63	3.74
0.64	5.44	72.7	58.0	65.4	8.8	12.85	0.38	6.62	3.67
0.65	5.52	72.7	58.0	65.4	8.8	12.78	0.42	6.60	3.61
0.66	5.60	72.7	58.0	65.4	8.8	12.69	0.46	6.58	3.54
0.67	5.68	72.8	58.0	65.4	8.8	12.59	0.51	6.55	3.48
0.68	5.77	72.8	58.0	65.4	8.9	12.49	0.55	6.52	3.42
0.69	5.85	72.8	58.0	65.4	8.9	12.37	0.60	6.49	3.36
0.70	5.93	72.8	58.0	65.4	8.9	12.25	0.65	6.45	3.30
0.71	6.01	72.8	58.0	65.4	8.9	12.13	0.69	6.41	3.24
0.72	6.09	72.8	58.0	65.4	8.9	12.00	0.74	6.37	3.19
0.73	6.17	72.8	58.0	65.4	8.9	11.86	0.79	6.33	3.13
0.74	6.25	72.8	58.0	65.4	8.9	11.72	0.84	6.28	3.07
0.75	6.33	72.8	58.0	65.4	8.9	11.58	0.90	6.24	3.01
0.76	6.41	72.9	58.0	65.4	8.9	11.44	0.95	6.20	2.96
0.77	6.49	72.9	58.0	65.4	9.0	11.30	1.01	6.15	2.90

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	6.58	72.9	58.0	65.4	9.0	11.16	1.06	6.11	2.84
0.79	6.66	72.9	58.0	65.4	9.0	11.03	1.12	6.07	2.79
0.80	6.74	72.9	58.0	65.5	9.0	10.89	1.18	6.04	2.73
0.81	6.82	72.9	58.0	65.5	9.0	10.76	1.24	6.00	2.68
0.82	6.90	72.9	58.0	65.5	9.0	10.64	1.31	5.97	2.62
0.83	6.98	72.9	58.0	65.5	9.0	10.52	1.37	5.95	2.57
0.84	7.06	72.9	58.0	65.5	9.0	10.41	1.43	5.92	2.51
0.85	7.14	72.9	58.0	65.5	9.1	10.31	1.49	5.90	2.46
0.86	7.23	72.9	58.0	65.5	9.1	10.22	1.55	5.88	2.40
0.87	7.31	72.9	58.0	65.5	9.1	10.13	1.60	5.87	2.35
0.88	7.39	72.9	58.0	65.5	9.1	10.06	1.66	5.86	2.30
0.89	7.47	72.9	58.0	65.5	9.1	9.99	1.71	5.85	2.24
0.90	7.55	72.9	58.0	65.5	9.1	9.94	1.75	5.84	2.20
0.91	7.63	72.9	58.0	65.5	9.1	9.89	1.80	5.84	2.16
0.92	7.72	72.9	58.0	65.5	9.1	9.85	1.84	5.85	2.11
0.93	7.80	72.9	58.0	65.5	9.2	9.82	1.88	5.85	2.07
0.94	7.88	72.9	58.0	65.5	9.2	9.79	1.92	5.85	2.03
0.95	7.96	73.0	58.0	65.5	9.2	9.77	1.96	5.86	1.98
0.96	8.04	73.0	58.0	65.5	9.2	9.75	1.99	5.87	1.94
0.97	8.12	73.0	58.0	65.5	9.2	9.74	2.03	5.88	1.90
0.98	8.21	73.0	58.0	65.5	9.2	9.72	2.07	5.90	1.86
0.99	8.29	73.0	58.0	65.5	9.2	9.72	2.11	5.91	1.82

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	3.00	2.89	5.89	0.55	6.44	3.00	0.40	0.10
0.0	0.37	46.96	3.84	50.80	20.43	71.23	7.38	21.94	87.58
0.01	0.45	45.50	3.85	49.35	19.89	69.24	7.37	21.73	83.33
0.02	0.53	43.68	3.83	47.51	19.35	66.86	7.37	21.51	79.25
0.03	0.60	41.94	3.80	45.74	18.83	64.57	7.35	21.29	75.35
0.04	0.68	40.27	3.78	44.05	18.31	62.36	7.33	21.08	71.61
0.05	0.76	38.67	3.76	42.43	17.81	60.24	7.30	20.86	68.04
0.06	0.84	37.13	3.74	40.87	17.39	58.26	7.20	20.65	64.63
0.07	0.92	35.71	3.73	39.44	17.00	56.45	7.10	20.44	61.48
0.08	0.99	34.46	3.73	38.20	16.62	54.82	7.02	20.25	58.72
0.09	1.07	33.26	3.74	37.00	16.24	53.24	6.93	20.05	56.07
0.10	1.15	32.10	3.74	35.84	15.88	51.73	6.83	19.86	53.54
0.11	1.23	30.99	3.74	34.74	15.54	50.28	6.72	19.67	51.11
0.12	1.31	29.92	3.75	33.67	15.21	48.88	6.61	19.47	48.78
0.13	1.39	28.89	3.76	32.64	14.88	47.53	6.49	19.28	46.56
0.14	1.46	27.90	3.76	31.66	14.56	46.22	6.38	19.09	44.44
0.15	1.54	26.94	3.77	30.71	14.23	44.94	6.28	18.90	42.40
0.16	1.62	26.03	3.77	29.80	13.90	43.71	6.18	18.71	40.47
0.17	1.70	25.15	3.78	28.93	13.58	42.51	6.09	18.52	38.62
0.18	1.78	24.30	3.79	28.09	13.26	41.36	6.00	18.34	36.85
0.19	1.86	23.49	3.80	27.29	12.95	40.24	5.91	18.15	35.17
0.20	1.94	22.71	3.81	26.52	12.65	39.17	5.82	17.96	33.56
0.21	2.02	21.96	3.82	25.78	12.35	38.13	5.72	17.78	32.03
0.22	2.09	21.24	3.83	25.06	12.07	37.13	5.63	17.60	30.57
0.23	2.17	20.54	3.84	24.38	11.78	36.16	5.54	17.42	29.18
0.24	2.25	19.87	3.85	23.72	11.51	35.23	5.44	17.24	27.86
0.25	2.33	19.23	3.86	23.09	11.24	34.34	5.35	17.06	26.60

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	2.41	18.62	3.87	22.49	10.99	33.47	5.26	16.88	25.40
0.27	2.49	18.02	3.88	21.90	10.73	32.64	5.16	16.71	24.25
0.28	2.57	17.45	3.90	21.35	10.49	31.83	5.07	16.53	23.16
0.29	2.65	16.90	3.91	20.81	10.25	31.06	4.97	16.36	22.12
0.30	2.73	16.37	3.92	20.29	10.02	30.31	4.88	16.19	21.14
0.31	2.81	15.86	3.94	19.80	9.79	29.59	4.79	16.02	20.20
0.32	2.88	15.37	3.95	19.32	9.57	28.89	4.70	15.85	19.30
0.33	2.96	14.90	3.97	18.87	9.36	28.22	4.61	15.68	18.45
0.34	3.04	14.45	3.98	18.43	9.15	27.58	4.52	15.52	17.63
0.35	3.12	14.01	4.00	18.00	8.95	26.95	4.43	15.36	16.86
0.36	3.20	13.59	4.01	17.60	8.75	26.35	4.34	15.20	16.12
0.37	3.28	13.18	4.03	17.21	8.56	25.77	4.25	15.04	15.42
0.38	3.36	12.79	4.04	16.83	8.38	25.21	4.16	14.88	14.75
0.39	3.44	12.41	4.06	16.47	8.20	24.67	4.08	14.72	14.11
0.40	3.52	12.04	4.08	16.12	8.02	24.15	3.99	14.57	13.50
0.41	3.60	11.69	4.10	15.79	7.85	23.64	3.91	14.41	12.92
0.42	3.68	11.35	4.11	15.47	7.69	23.15	3.83	14.26	12.37
0.43	3.76	11.02	4.13	15.16	7.53	22.69	3.75	14.11	11.85
0.44	3.84	10.71	4.15	14.86	7.37	22.23	3.67	13.96	11.34
0.45	3.92	10.40	4.17	14.57	7.22	21.79	3.59	13.82	10.86
0.46	4.00	10.11	4.19	14.29	7.08	21.37	3.51	13.67	10.41
0.47	4.08	9.82	4.21	14.03	6.93	20.96	3.43	13.53	9.97
0.48	4.16	9.55	4.23	13.77	6.79	20.57	3.36	13.39	9.56
0.49	4.24	9.28	4.25	13.53	6.66	20.18	3.29	13.25	9.16
0.50	4.32	9.02	4.27	13.29	6.53	19.82	3.21	13.11	8.78
0.51	4.40	8.77	4.29	13.06	6.40	19.46	3.14	12.97	8.42

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.48	8.53	4.30	12.83	6.28	19.11	3.07	12.83	8.07
0.53	4.56	8.29	4.32	12.62	6.15	18.77	3.04	12.70	7.74
0.54	4.64	8.07	4.34	12.41	6.04	18.45	3.01	12.57	7.42
0.55	4.72	7.84	4.36	12.20	5.92	18.13	3.00	12.43	7.11
0.56	4.80	7.62	4.38	12.00	5.81	17.81	3.00	12.30	6.81
0.57	4.88	7.41	4.40	11.81	5.70	17.51	3.00	12.17	6.52
0.58	4.96	7.20	4.41	11.61	5.60	17.21	3.00	12.04	6.24
0.59	5.04	7.00	4.43	11.43	5.50	16.92	3.00	11.91	5.97
0.60	5.12	6.80	4.44	11.24	5.40	16.64	3.00	11.78	5.71
0.61	5.20	6.61	4.45	11.06	5.30	16.36	3.00	11.65	5.46
0.62	5.28	6.42	4.47	10.88	5.20	16.09	3.00	11.53	5.22
0.63	5.36	6.23	4.48	10.71	5.11	15.82	3.00	11.40	4.99
0.64	5.44	6.05	4.49	10.54	5.02	15.56	3.00	11.27	4.76
0.65	5.52	5.87	4.50	10.37	4.93	15.30	3.00	11.15	4.54
0.66	5.60	5.70	4.51	10.20	4.85	15.05	3.00	11.02	4.33
0.67	5.68	5.52	4.52	10.04	4.76	14.80	3.00	10.90	4.12
0.68	5.77	5.36	4.52	9.88	4.68	14.56	3.00	10.77	3.92
0.69	5.85	5.19	4.53	9.72	4.60	14.32	3.00	10.65	3.73
0.70	5.93	5.04	4.54	9.58	4.52	14.09	3.00	10.53	3.55
0.71	6.01	4.89	4.54	9.43	4.44	13.87	3.00	10.41	3.38
0.72	6.09	4.74	4.55	9.29	4.36	13.65	3.00	10.29	3.22
0.73	6.17	4.60	4.56	9.16	4.28	13.44	3.00	10.17	3.06
0.74	6.25	4.46	4.57	9.04	4.20	13.24	3.00	10.06	2.92
0.75	6.33	4.33	4.58	8.91	4.12	13.04	3.00	9.95	2.78
0.76	6.41	4.20	4.59	8.80	4.05	12.84	3.00	9.83	2.65
0.77	6.49	4.08	4.60	8.68	3.97	12.65	3.00	9.72	2.52

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

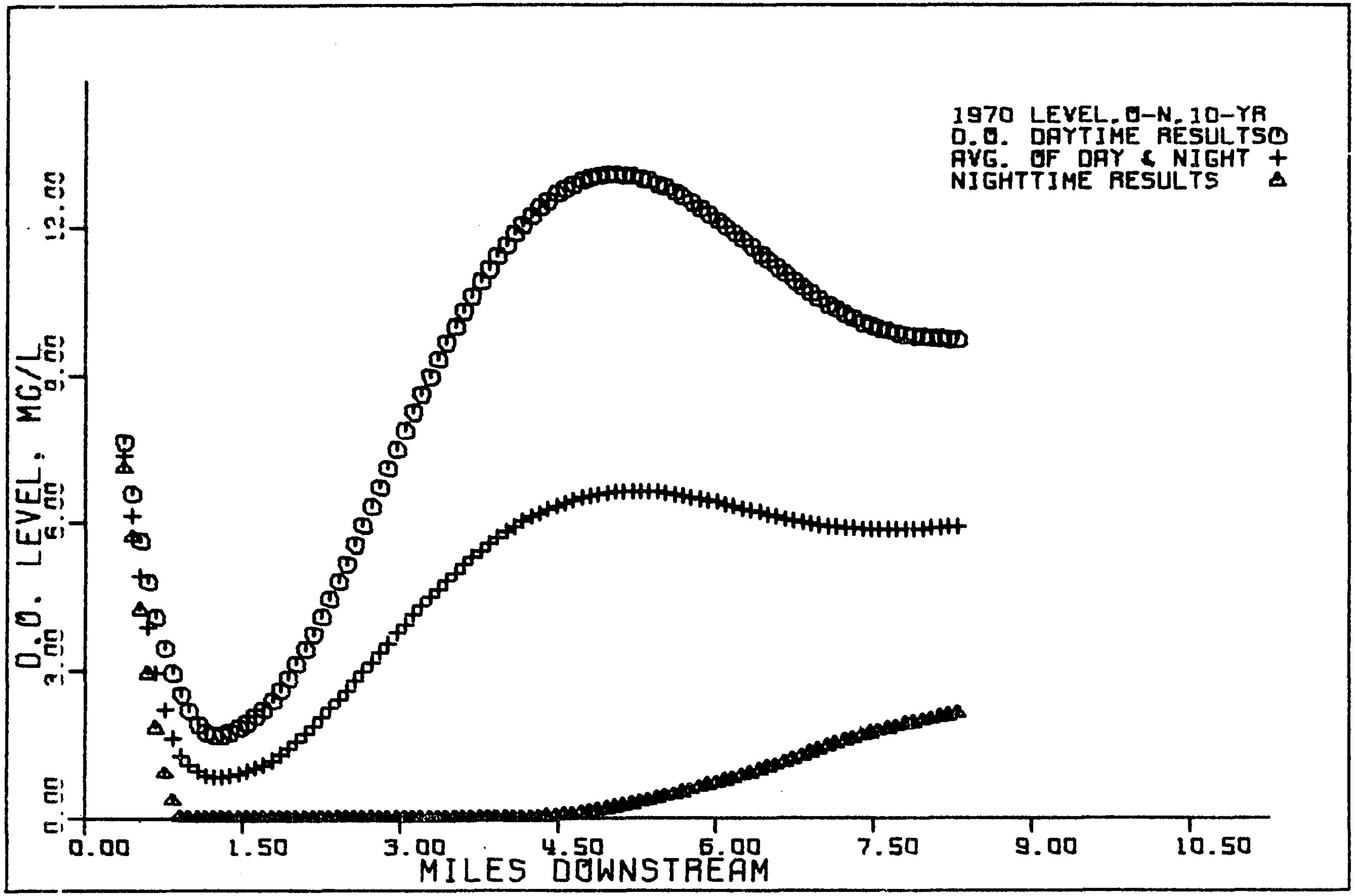
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	6.58	3.96	4.61	8.57	3.89	12.47	3.00	9.61	2.40
0.79	6.66	3.84	4.63	8.47	3.81	12.29	3.00	9.50	2.28
0.80	6.74	3.73	4.64	8.37	3.74	12.11	3.00	9.40	2.18
0.81	6.82	3.62	4.65	8.27	3.66	11.94	3.00	9.29	2.07
0.82	6.90	3.52	4.66	8.18	3.59	11.77	3.00	9.19	1.97
0.83	6.98	3.42	4.67	8.09	3.51	11.60	3.00	9.08	1.88
0.84	7.06	3.32	4.69	8.01	3.44	11.44	3.00	8.98	1.79
0.85	7.14	3.23	4.70	7.93	3.36	11.29	3.00	8.88	1.71
0.86	7.23	3.13	4.71	7.85	3.29	11.13	3.00	8.78	1.63
0.87	7.31	3.04	4.73	7.77	3.21	10.98	3.00	8.68	1.55
0.88	7.39	2.96	4.74	7.70	3.14	10.84	3.00	8.59	1.48
0.89	7.47	2.87	4.76	7.63	3.07	10.70	3.00	8.49	1.41
0.90	7.55	2.79	4.77	7.56	3.00	10.56	3.00	8.39	1.34
0.91	7.63	2.71	4.78	7.50	2.93	10.42	3.00	8.30	1.28
0.92	7.72	2.64	4.80	7.44	2.86	10.29	3.00	8.21	1.22
0.93	7.80	2.56	4.81	7.38	2.79	10.16	3.00	8.12	1.16
0.94	7.88	2.49	4.83	7.32	2.72	10.04	3.00	8.03	1.11
0.95	7.96	2.42	4.84	7.27	2.65	9.92	3.00	7.94	1.05
0.96	8.04	2.36	4.86	7.21	2.59	9.80	3.00	7.85	1.00
0.97	8.12	2.29	4.87	7.16	2.52	9.69	3.00	7.76	0.96
0.98	8.21	2.23	4.89	7.12	2.46	9.57	3.00	7.68	0.91
0.99	8.29	2.17	4.91	7.07	2.40	9.47	3.00	7.59	0.87

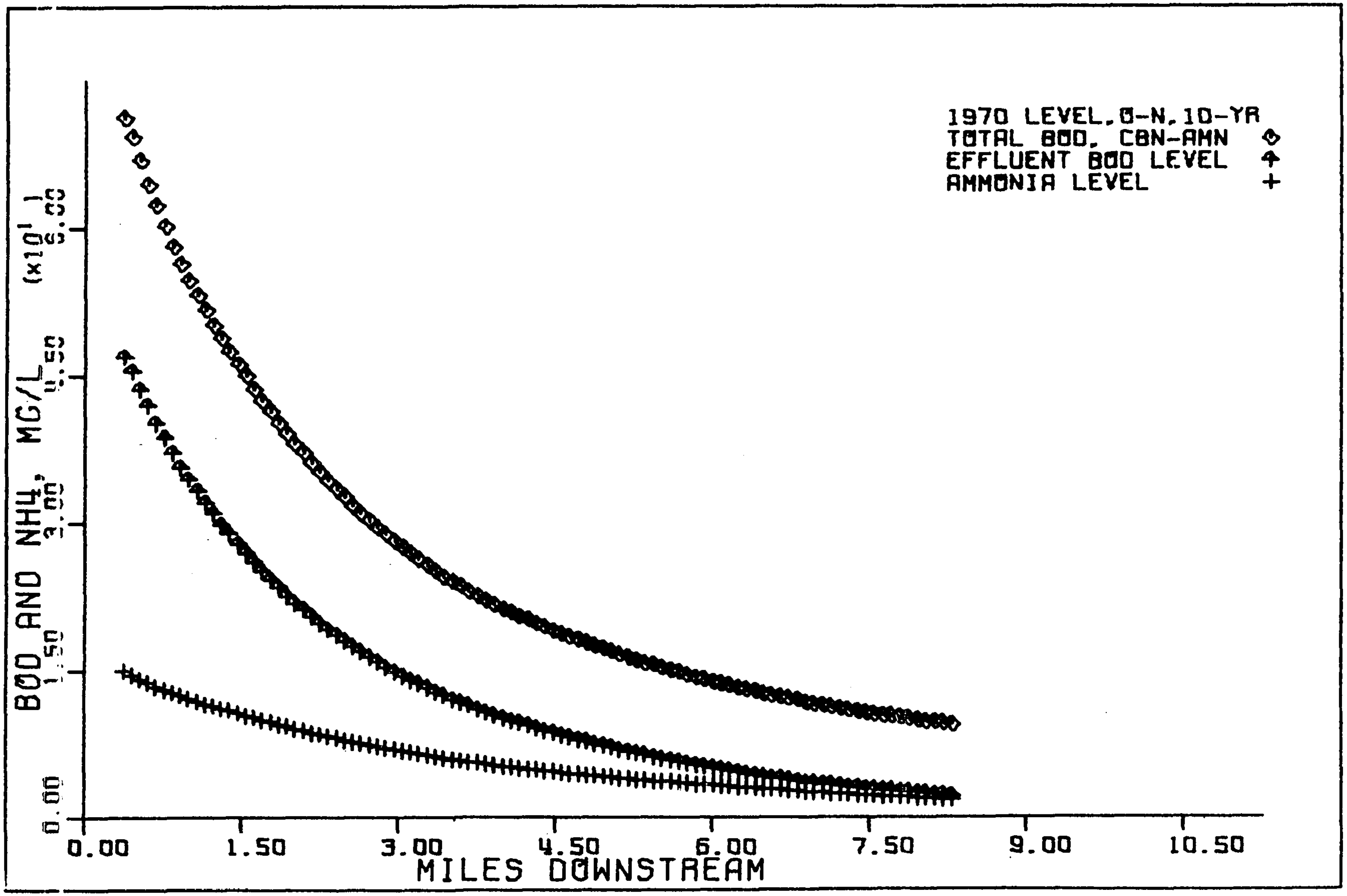
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	7.65	0.37	0.0	7.11	0.37	0.0
MINIMUM DO, MG/L	1.68	1.23	0.11	0.0	0.92	0.07
FINAL DO, MG/L	10.89	6.74	0.80	1.18	6.74	0.80
DO DEFICIT						
INITIAL, MG/L	1.78	0.37	0.0	2.53	0.37	0.0
FINAL, MG/L	-2.60	6.74	0.80	8.67	6.74	0.80
RIVER DISCHARGE						
INITIAL, CFS	8.04	0.37	0.0	8.04	0.37	0.0
FINAL, CFS	9.00	6.74	0.80	9.00	6.74	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	61.62	0.37	0.0	59.75	0.37	0.0
FINAL, DEG F	72.89	6.74	0.80	58.02	6.74	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	46.96	0.37	0.0	46.96	0.37	0.0
FINAL BOD, MG/L	2.08	6.74	0.80	5.39	6.74	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.13	0.37	0.0	0.13	0.37	0.0
FINAL BOD IN RIVER	3.98	6.74	0.80	5.30	6.74	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	20.43	0.37	0.0	20.43	0.37	0.0
FINAL BOD, MG/L	0.81	6.74	0.80	6.67	6.74	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	70.28	0.37	0.0	72.18	0.37	0.0
FINAL VALUE, MG/L	6.87	6.74	0.80	17.35	6.74	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	14.94	0.37	0.0	14.94	0.37	0.0
FINAL VALUE, MG/L	0.59	6.74	0.80	4.87	6.74	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	7.38	0.37	0.0	7.38	0.37	0.0
FINAL VALUE, MG/L	3.00	6.74	0.80	3.00	6.74	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	21.94	0.37	0.0	21.94	0.37	0.0
FINAL VALUE, MG/L	6.98	6.74	0.80	11.82	6.74	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	87.58	0.37	0.0	87.58	0.37	0.0
FINAL PERCENT	0.48	6.74	0.80	3.87	6.74	0.80


1970 LEVEL, 0-N, 10-YR
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM


1970 LEVEL, 0-N, 10-YR
TOTAL BOD, CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
(x10[1])
0.00
1.50
3.00
4.50
6.00
0.00
1.50
3.00
4.50
6.00
7.50
9.00
10.50
MILES DOWNSTREAM

I. Computer Results for 1970 Status Study, Winter, 10 Yr, Low Reaeration Coefficients

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.72	50.00	75.00	0.0	55.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.50	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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              AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

      INPUT DATA FOR THIS ANALYSIS

      STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
      RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
      SEASON : WINTER

 GAMMA1 =    0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    5.76 CFS, RIVER Q =   0.50 CFS, TOTAL Q =   6.26 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		0.5	12.79	9.95		0.40
0.0	0.37	48.6	48.6	48.6	6.3	8.57	8.34	8.45	23.03
0.02	0.51	46.8	46.8	46.8	6.3	5.97	6.14	6.06	22.29
0.04	0.65	45.2	45.2	45.2	6.3	4.11	4.21	4.16	21.62
0.06	0.80	43.7	43.7	43.7	6.3	2.84	2.89	2.87	21.02
0.08	0.94	42.5	42.5	42.5	6.3	2.01	2.02	2.01	20.46
0.10	1.08	41.3	41.3	41.3	6.3	1.49	1.48	1.48	19.94
0.12	1.22	40.3	40.3	40.3	6.3	1.39	1.36	1.37	19.53
0.14	1.37	39.4	39.4	39.4	6.4	1.45	1.41	1.43	19.16
0.16	1.51	38.6	38.6	38.6	6.4	1.59	1.55	1.57	18.81
0.18	1.65	37.9	37.9	37.9	6.4	1.76	1.72	1.74	18.45
0.20	1.79	37.2	37.2	37.2	6.4	1.94	1.90	1.92	18.09
0.22	1.94	36.7	36.7	36.7	6.4	2.13	2.09	2.11	17.72
0.24	2.08	36.2	36.2	36.2	6.4	2.34	2.29	2.32	17.37
0.26	2.22	35.7	35.7	35.7	6.4	2.59	2.53	2.56	17.02
0.28	2.37	35.3	35.3	35.3	6.5	2.87	2.80	2.83	16.69
0.30	2.51	35.0	35.0	35.0	6.5	3.15	3.08	3.12	16.37
0.32	2.66	34.6	34.6	34.6	6.5	3.45	3.38	3.41	16.06
0.34	2.80	34.3	34.3	34.3	6.5	3.74	3.67	3.71	15.76
0.36	2.94	34.1	34.1	34.1	6.5	4.04	3.97	4.00	15.47
0.38	3.09	33.9	33.9	33.9	6.5	4.33	4.26	4.30	15.19
0.40	3.23	33.7	33.7	33.7	6.5	4.62	4.55	4.59	14.91
0.42	3.38	33.5	33.5	33.5	6.6	4.90	4.83	4.87	14.64
0.44	3.52	33.3	33.3	33.3	6.6	5.17	5.11	5.14	14.38
0.46	3.66	33.2	33.2	33.2	6.6	5.44	5.37	5.40	14.12
0.48	3.81	33.0	33.0	33.0	6.6	5.69	5.63	5.66	13.88
0.50	3.95	32.9	32.9	32.9	6.6	5.94	5.87	5.91	13.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.10	32.8	32.8	32.8	6.6	6.17	6.11	6.14	13.39
0.54	4.24	32.7	32.7	32.7	6.6	6.40	6.34	6.37	13.16
0.56	4.39	32.7	32.7	32.7	6.7	6.62	6.56	6.59	12.93
0.58	4.53	32.6	32.6	32.6	6.7	6.82	6.77	6.80	12.71
0.60	4.68	32.5	32.5	32.5	6.7	7.02	6.97	7.00	12.49
0.62	4.83	32.5	32.5	32.5	6.7	7.21	7.16	7.19	12.27
0.64	4.97	32.4	32.4	32.4	6.7	6.51	6.45	6.48	12.06
0.66	5.12	32.4	32.4	32.4	6.7	5.82	5.76	5.79	11.86
0.68	5.26	32.3	32.3	32.3	6.7	5.16	5.10	5.13	11.65
0.70	5.41	32.3	32.3	32.3	6.8	4.53	4.46	4.49	11.45
0.72	5.55	32.3	32.3	32.3	6.8	3.91	3.84	3.88	11.26
0.74	5.70	32.2	32.2	32.2	6.8	3.32	3.24	3.28	11.07
0.76	5.85	32.2	32.2	32.2	6.8	2.75	2.67	2.71	10.88
0.78	5.99	32.2	32.2	32.2	6.8	2.20	2.11	2.16	10.69
0.80	6.14	32.2	32.2	32.2	6.8	1.67	1.58	1.62	10.51
0.82	6.29	32.1	32.1	32.1	6.9	1.19	1.11	1.15	10.35
0.84	6.43	32.1	32.1	32.1	6.9	0.79	0.72	0.75	10.22
0.86	6.58	32.1	32.1	32.1	6.9	0.45	0.38	0.41	10.11
0.88	6.73	32.1	32.1	32.1	6.9	0.15	0.09	0.12	10.02
0.90	6.87	32.1	32.1	32.1	6.9	0.0	0.0	0.0	9.92
0.92	7.02	32.1	32.1	32.1	6.9	0.0	0.0	0.0	9.83
0.94	7.17	32.1	32.1	32.1	6.9	0.0	0.0	0.0	9.74
0.96	7.32	32.1	32.1	32.1	7.0	0.0	0.0	0.0	9.64
0.98	7.46	32.1	32.1	32.1	7.0	0.0	0.0	0.0	9.55
1.00	7.61	32.1	32.1	32.1	7.0	0.0	0.0	0.0	9.46
1.02	7.76	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.37

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	7.91	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.29
1.06	8.06	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.20
1.08	8.20	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.11
1.10	8.35	32.0	32.0	32.0	7.1	0.0	0.0	0.0	9.03
1.12	8.50	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.94
1.14	8.65	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.86
1.16	8.80	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.77
1.18	8.95	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.69
1.20	9.10	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.61
1.22	9.25	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.53
1.24	9.39	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.45
1.26	9.54	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.37
1.28	9.69	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.29
1.30	9.84	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.21
1.32	9.99	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.14
1.34	10.14	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.06
1.36	10.29	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.99
1.38	10.44	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.91
1.40	10.59	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.84
1.42	10.74	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.76
1.44	10.89	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.69
1.46	11.04	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.62
1.48	11.19	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.55
1.50	11.34	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.48
1.52	11.49	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.41
1.54	11.65	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.34

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	11.80	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.27
1.58	11.95	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.20
1.60	12.10	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.14
1.62	12.25	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.07
1.64	12.40	32.0	32.0	32.0	7.5	0.0	0.0	0.0	7.00
1.66	12.55	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.94
1.68	12.70	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.87
1.70	12.86	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.81
1.72	13.01	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.75
1.74	13.16	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.68
1.76	13.31	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.62
1.78	13.46	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.56
1.80	13.62	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.50
1.82	13.77	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.44
1.84	13.92	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.38
1.86	14.07	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.32
1.88	14.23	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.26
1.90	14.38	32.0	32.0	32.0	7.7	0.0	0.0	0.0	6.20
1.92	14.53	32.0	32.0	32.0	7.7	0.0	0.0	0.0	6.15
1.94	14.69	32.0	32.0	32.0	7.7	0.0	0.0	0.0	6.09
1.96	14.84	32.0	32.0	32.0	7.7	0.0	0.0	0.0	6.03
1.98	14.99	32.0	32.0	32.0	7.7	0.0	0.0	0.0	5.98

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	1.83	3.83	0.55	4.38	3.00	0.40	0.10
0.0	0.37	67.47	2.18	69.65	31.51	101.16	4.84	27.64	92.02
0.02	0.51	63.93	2.24	66.17	30.50	96.67	5.04	27.30	85.58
0.04	0.65	60.10	2.27	62.37	29.58	91.95	5.20	26.98	79.86
0.06	0.80	56.67	2.31	58.99	28.75	87.73	5.34	26.69	74.75
0.08	0.94	53.59	2.35	55.94	27.98	83.92	5.46	26.41	70.14
0.10	1.08	50.78	2.40	53.18	27.28	80.46	5.57	26.15	65.95
0.12	1.22	48.22	2.45	50.67	26.72	77.39	5.56	25.90	62.13
0.14	1.37	45.87	2.50	48.37	26.22	74.58	5.53	25.66	58.63
0.16	1.51	43.70	2.55	46.25	25.73	71.97	5.51	25.43	55.40
0.18	1.65	41.68	2.60	44.28	25.24	69.52	5.51	25.21	52.41
0.20	1.79	39.81	2.66	42.46	24.75	67.21	5.53	25.00	49.63
0.22	1.94	38.06	2.71	40.77	24.25	65.02	5.58	24.79	47.05
0.24	2.08	36.42	2.77	39.18	23.76	62.94	5.63	24.58	44.63
0.26	2.22	34.88	2.82	37.70	23.29	60.99	5.68	24.39	42.37
0.28	2.37	33.43	2.88	36.31	22.83	59.14	5.72	24.19	40.25
0.30	2.51	32.07	2.93	35.00	22.39	57.39	5.76	24.00	38.26
0.32	2.66	30.78	2.99	33.77	21.97	55.74	5.80	23.82	36.38
0.34	2.80	29.56	3.04	32.60	21.56	54.16	5.83	23.63	34.61
0.36	2.94	28.40	3.10	31.50	21.16	52.66	5.85	23.45	32.94
0.38	3.09	27.30	3.15	30.45	20.77	51.23	5.88	23.28	31.36
0.40	3.23	26.26	3.20	29.46	20.40	49.86	5.90	23.10	29.87
0.42	3.38	25.26	3.26	28.52	20.03	48.55	5.92	22.93	28.45
0.44	3.52	24.32	3.31	27.63	19.67	47.30	5.93	22.76	27.11
0.46	3.66	23.42	3.36	26.78	19.32	46.10	5.95	22.59	25.83
0.48	3.81	22.55	3.41	25.97	18.98	44.95	5.96	22.43	24.62
0.50	3.95	21.73	3.47	25.20	18.65	43.85	5.97	22.26	23.47

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.10	20.95	3.52	24.46	18.32	42.78	5.97	22.10	22.38
0.54	4.24	20.19	3.57	23.76	18.00	41.76	5.98	21.94	21.34
0.56	4.39	19.47	3.62	23.09	17.69	40.78	5.98	21.78	20.35
0.58	4.53	18.78	3.67	22.45	17.38	39.83	5.98	21.62	19.41
0.60	4.68	18.12	3.72	21.84	17.08	38.92	5.98	21.47	18.52
0.62	4.83	17.49	3.76	21.25	16.79	38.04	5.98	21.32	17.67
0.64	4.97	16.88	3.81	20.69	16.50	37.20	5.97	21.16	16.85
0.66	5.12	16.30	3.86	20.16	16.22	36.38	5.97	21.01	16.08
0.68	5.26	15.74	3.91	19.65	15.94	35.59	5.96	20.86	15.34
0.70	5.41	15.20	3.95	19.16	15.67	34.82	5.95	20.71	14.64
0.72	5.55	14.69	4.00	18.68	15.40	34.09	5.94	20.57	13.97
0.74	5.70	14.19	4.04	18.23	15.14	33.37	5.93	20.42	13.33
0.76	5.85	13.71	4.09	17.80	14.88	32.68	5.92	20.28	12.72
0.78	5.99	13.26	4.13	17.39	14.63	32.02	5.91	20.13	12.14
0.80	6.14	12.82	4.18	16.99	14.38	31.37	5.89	19.99	11.59
0.82	6.29	12.39	4.22	16.61	14.17	30.78	5.85	19.85	11.06
0.84	6.43	11.98	4.26	16.24	13.99	30.23	5.78	19.71	10.56
0.86	6.58	11.59	4.30	15.89	13.84	29.73	5.69	19.57	10.08
0.88	6.73	11.23	4.35	15.58	13.70	29.28	5.61	19.44	9.64
0.90	6.87	10.93	4.42	15.34	13.57	28.92	5.54	19.32	9.28
0.92	7.02	10.65	4.49	15.14	13.45	28.59	5.47	19.21	8.96
0.94	7.17	10.39	4.56	14.95	13.32	28.27	5.40	19.10	8.65
0.96	7.32	10.13	4.63	14.77	13.19	27.96	5.34	18.98	8.35
0.98	7.46	9.88	4.70	14.59	13.07	27.65	5.27	18.88	8.06
1.00	7.61	9.64	4.77	14.41	12.95	27.36	5.21	18.77	7.78
1.02	7.76	9.40	4.84	14.24	12.82	27.07	5.15	18.66	7.51

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	7.91	9.17	4.91	14.08	12.70	26.78	5.09	18.55	7.25
1.06	8.06	8.95	4.97	13.92	12.58	26.50	5.02	18.44	7.00
1.08	8.20	8.73	5.04	13.77	12.46	26.23	4.96	18.34	6.76
1.10	8.35	8.52	5.10	13.62	12.35	25.96	4.91	18.23	6.53
1.12	8.50	8.31	5.16	13.47	12.23	25.70	4.85	18.13	6.30
1.14	8.65	8.11	5.23	13.33	12.12	25.45	4.79	18.02	6.08
1.16	8.80	7.91	5.29	13.20	12.00	25.20	4.73	17.92	5.87
1.18	8.95	7.72	5.35	13.07	11.89	24.96	4.68	17.82	5.67
1.20	9.10	7.54	5.41	12.94	11.78	24.72	4.62	17.71	5.47
1.22	9.25	7.35	5.46	12.82	11.67	24.49	4.57	17.61	5.29
1.24	9.39	7.18	5.52	12.70	11.56	24.26	4.51	17.51	5.10
1.26	9.54	7.01	5.58	12.58	11.45	24.03	4.46	17.41	4.93
1.28	9.69	6.84	5.63	12.47	11.34	23.82	4.41	17.31	4.76
1.30	9.84	6.68	5.69	12.37	11.24	23.60	4.35	17.21	4.59
1.32	9.99	6.52	5.74	12.26	11.13	23.39	4.30	17.11	4.44
1.34	10.14	6.36	5.80	12.16	11.03	23.19	4.25	17.02	4.28
1.36	10.29	6.21	5.85	12.06	10.92	22.99	4.20	16.92	4.13
1.38	10.44	6.06	5.90	11.97	10.82	22.79	4.15	16.82	3.99
1.40	10.59	5.92	5.96	11.88	10.72	22.60	4.11	16.73	3.85
1.42	10.74	5.78	6.01	11.79	10.62	22.41	4.06	16.63	3.72
1.44	10.89	5.65	6.06	11.70	10.52	22.22	4.01	16.54	3.59
1.46	11.04	5.51	6.11	11.62	10.42	22.04	3.96	16.44	3.47
1.48	11.19	5.38	6.16	11.54	10.33	21.87	3.92	16.35	3.35
1.50	11.34	5.26	6.21	11.46	10.23	21.69	3.87	16.26	3.23
1.52	11.49	5.14	6.25	11.39	10.13	21.52	3.83	16.16	3.12
1.54	11.65	5.02	6.30	11.32	10.04	21.36	3.78	16.07	3.02

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

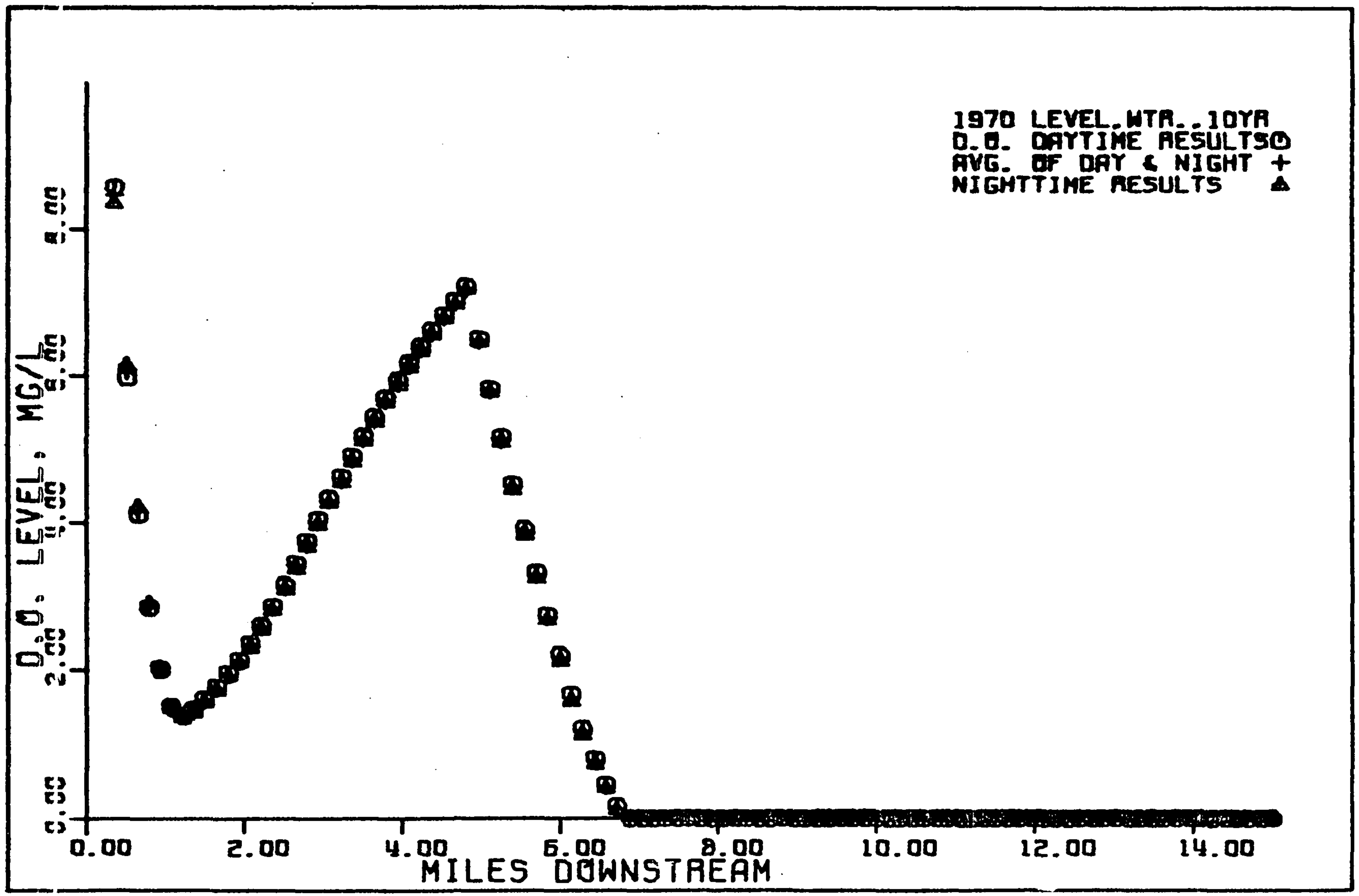
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	11.80	4.90	6.35	11.25	9.95	21.19	3.74	15.98	2.91
1.58	11.95	4.79	6.40	11.18	9.85	21.03	3.70	15.89	2.81
1.60	12.10	4.67	6.44	11.12	9.76	20.88	3.66	15.80	2.72
1.62	12.25	4.57	6.49	11.05	9.67	20.72	3.61	15.71	2.62
1.64	12.40	4.46	6.53	10.99	9.58	20.57	3.57	15.62	2.53
1.66	12.55	4.36	6.58	10.93	9.49	20.43	3.53	15.53	2.44
1.68	12.70	4.26	6.62	10.88	9.40	20.28	3.49	15.44	2.36
1.70	12.86	4.16	6.66	10.82	9.32	20.14	3.45	15.36	2.28
1.72	13.01	4.06	6.71	10.77	9.23	20.00	3.41	15.27	2.20
1.74	13.16	3.97	6.75	10.72	9.14	19.87	3.37	15.18	2.13
1.76	13.31	3.88	6.79	10.67	9.06	19.73	3.34	15.10	2.05
1.78	13.46	3.79	6.83	10.63	8.98	19.60	3.30	15.01	1.98
1.80	13.62	3.70	6.88	10.58	8.89	19.47	3.26	14.93	1.91
1.82	13.77	3.62	6.92	10.54	8.81	19.35	3.22	14.84	1.85
1.84	13.92	3.54	6.96	10.50	8.73	19.22	3.19	14.76	1.78
1.86	14.07	3.46	7.00	10.46	8.65	19.10	3.15	14.68	1.72
1.88	14.23	3.38	7.04	10.42	8.57	18.98	3.12	14.59	1.66
1.90	14.38	3.30	7.08	10.38	8.49	18.87	3.08	14.51	1.61
1.92	14.53	3.23	7.12	10.34	8.41	18.75	3.05	14.43	1.55
1.94	14.69	3.15	7.16	10.31	8.33	18.64	3.01	14.35	1.50
1.96	14.84	3.08	7.19	10.28	8.25	18.53	3.00	14.27	1.45
1.98	14.99	3.01	7.23	10.25	8.18	18.42	3.00	14.19	1.40

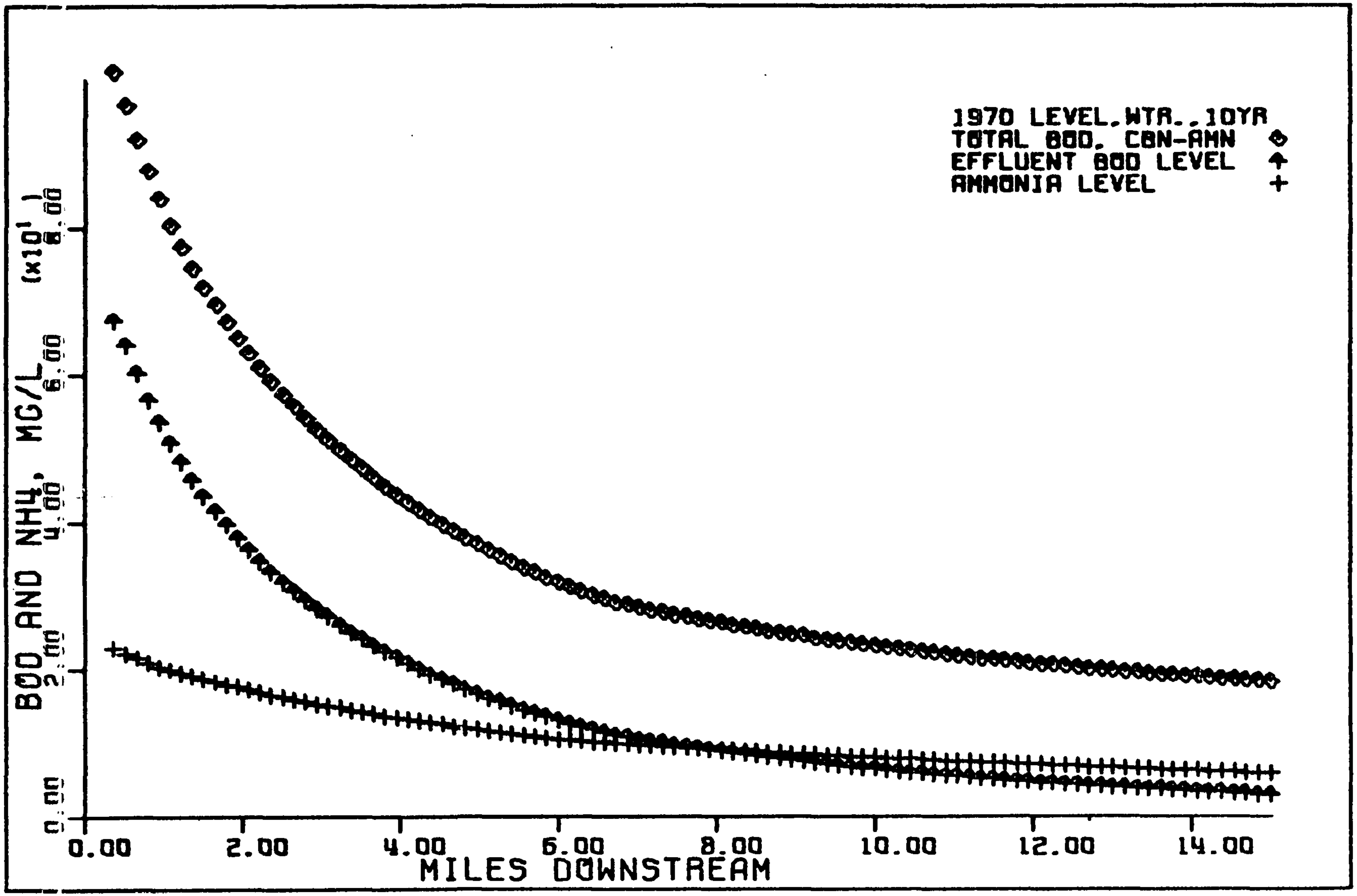
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.57	0.37	0.0	8.34	0.37	0.0
MINIMUM DO, MG/L	0.0	6.87	0.90	0.0	6.87	0.90
FINAL DO, MG/L	1.67	6.14	0.80	1.58	6.14	0.80
DO DEFICIT						
INITIAL, MG/L	2.58	0.37	0.0	2.81	0.37	0.0
FINAL, MG/L	12.51	6.14	0.80	12.60	6.14	0.80
RIVER DISCHARGE						
INITIAL, CFS	6.26	0.37	0.0	6.26	0.37	0.0
FINAL, CFS	6.84	6.14	0.80	6.84	6.14	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	48.56	0.37	0.0	48.56	0.37	0.0
FINAL, DEG F	32.17	6.14	0.80	32.17	6.14	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	67.47	0.37	0.0	67.47	0.37	0.0
FINAL BOD, MG/L	12.73	6.14	0.80	12.90	6.14	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.17	0.37	0.0	0.17	0.37	0.0
FINAL BOD IN RIVER	4.11	6.14	0.80	4.24	6.14	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	31.51	0.37	0.0	31.51	0.37	0.0
FINAL BOD, MG/L	14.37	6.14	0.80	14.39	6.14	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	100.81	0.37	0.0	101.51	0.37	0.0
FINAL VALUE, MG/L	31.21	6.14	0.80	31.53	6.14	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	23.03	0.37	0.0	23.03	0.37	0.0
FINAL VALUE, MG/L	10.51	6.14	0.80	10.52	6.14	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.84	0.37	0.0	4.84	0.37	0.0
FINAL VALUE, MG/L	5.90	6.14	0.80	5.88	6.14	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	27.64	0.37	0.0	27.64	0.37	0.0
FINAL VALUE, MG/L	19.99	6.14	0.80	19.99	6.14	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	92.02	0.37	0.0	92.02	0.37	0.0
FINAL PERCENT	11.59	6.14	0.80	11.59	6.14	0.80


1970 LEVEL.WTR..10YR
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


1970 LEVEL.WTR..10YR
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L (x10^{1})
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

J. Computer Results for 1970 Status Study, Winter, 10 Yr,

High Reaeration Coefficient

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
3.72	50.00	75.00	0.0	55.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIP	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
0.50	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.300	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                  AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
     SEASON : WINTER

 GAMMA1 =    0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    5.76 CFS, RIVER Q =   0.50 CFS, TOTAL Q =   6.26 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =    0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
```

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		0.5	12.79	9.95		0.40
0.0	0.37	48.6	48.6	48.6	6.3	8.57	8.34	8.45	23.03
0.02	0.51	46.8	46.8	46.8	6.3	5.97	6.14	6.06	22.29
0.04	0.65	45.2	45.2	45.2	6.3	4.11	4.21	4.16	21.62
0.06	0.80	43.7	43.7	43.7	6.3	2.84	2.89	2.87	21.02
0.08	0.94	42.5	42.5	42.5	6.3	2.01	2.02	2.01	20.46
0.10	1.08	41.3	41.3	41.3	6.3	1.49	1.48	1.48	19.94
0.12	1.22	40.3	40.3	40.3	6.3	1.39	1.36	1.37	19.53
0.14	1.37	39.4	39.4	39.4	6.4	1.45	1.41	1.43	19.16
0.16	1.51	38.6	38.6	38.6	6.4	1.59	1.55	1.57	18.81
0.18	1.65	37.9	37.9	37.9	6.4	1.76	1.72	1.74	18.45
0.20	1.79	37.2	37.2	37.2	6.4	1.94	1.90	1.92	18.09
0.22	1.94	36.7	36.7	36.7	6.4	2.13	2.09	2.11	17.72
0.24	2.08	36.2	36.2	36.2	6.4	2.34	2.29	2.32	17.37
0.26	2.22	35.7	35.7	35.7	6.4	2.59	2.53	2.56	17.02
0.28	2.37	35.3	35.3	35.3	6.5	2.87	2.80	2.83	16.69
0.30	2.51	35.0	35.0	35.0	6.5	3.15	3.08	3.12	16.37
0.32	2.66	34.6	34.6	34.6	6.5	3.45	3.38	3.41	16.06
0.34	2.80	34.3	34.3	34.3	6.5	3.74	3.67	3.71	15.76
0.36	2.94	34.1	34.1	34.1	6.5	4.04	3.97	4.00	15.47
0.38	3.09	33.9	33.9	33.9	6.5	4.33	4.26	4.30	15.19
0.40	3.23	33.7	33.7	33.7	6.5	4.62	4.55	4.59	14.91
0.42	3.38	33.5	33.5	33.5	6.6	4.90	4.83	4.87	14.64
0.44	3.52	33.3	33.3	33.3	6.6	5.17	5.11	5.14	14.38
0.46	3.66	33.2	33.2	33.2	6.6	5.44	5.37	5.40	14.12
0.48	3.81	33.0	33.0	33.0	6.6	5.69	5.63	5.66	13.88
0.50	3.95	32.9	32.9	32.9	6.6	5.94	5.87	5.91	13.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	4.10	32.8	32.8	32.8	6.6	6.17	6.11	6.14	13.39
0.54	4.24	32.7	32.7	32.7	6.6	6.40	6.34	6.37	13.16
0.56	4.39	32.7	32.7	32.7	6.7	6.62	6.56	6.59	12.93
0.58	4.53	32.6	32.6	32.6	6.7	6.82	6.77	6.80	12.71
0.60	4.68	32.5	32.5	32.5	6.7	7.02	6.97	7.00	12.49
0.62	4.83	32.5	32.5	32.5	6.7	7.21	7.16	7.19	12.27
0.64	4.97	32.4	32.4	32.4	6.7	6.54	6.48	6.51	12.06
0.66	5.12	32.4	32.4	32.4	6.7	5.89	5.83	5.86	11.86
0.68	5.26	32.3	32.3	32.3	6.7	5.27	5.20	5.23	11.65
0.70	5.41	32.3	32.3	32.3	6.8	4.67	4.60	4.63	11.45
0.72	5.55	32.3	32.3	32.3	6.8	4.10	4.02	4.06	11.26
0.74	5.70	32.2	32.2	32.2	6.8	3.55	3.47	3.51	11.07
0.76	5.85	32.2	32.2	32.2	6.8	3.02	2.94	2.98	10.88
0.78	5.99	32.2	32.2	32.2	6.8	2.52	2.44	2.48	10.69
0.80	6.14	32.2	32.2	32.2	6.8	2.04	1.95	2.00	10.51
0.82	6.29	32.1	32.1	32.1	6.9	1.58	1.49	1.54	10.34
0.84	6.43	32.1	32.1	32.1	6.9	1.18	1.11	1.15	10.19
0.86	6.58	32.1	32.1	32.1	6.9	0.85	0.78	0.82	10.06
0.88	6.73	32.1	32.1	32.1	6.9	0.57	0.51	0.54	9.95
0.90	6.87	32.1	32.1	32.1	6.9	0.34	0.28	0.31	9.85
0.92	7.02	32.1	32.1	32.1	6.9	0.13	0.07	0.10	9.76
0.94	7.17	32.1	32.1	32.1	6.9	0.0	0.0	0.0	9.66
0.96	7.32	32.1	32.1	32.1	7.0	0.0	0.0	0.0	9.57
0.98	7.46	32.1	32.1	32.1	7.0	0.0	0.0	0.0	9.48
1.00	7.61	32.1	32.1	32.1	7.0	0.0	0.0	0.0	9.39
1.02	7.76	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.30

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	7.91	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.22
1.06	8.06	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.13
1.08	8.20	32.0	32.0	32.0	7.0	0.0	0.0	0.0	9.04
1.10	8.35	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.96
1.12	8.50	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.87
1.14	8.65	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.79
1.16	8.80	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.71
1.18	8.95	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.63
1.20	9.10	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.55
1.22	9.25	32.0	32.0	32.0	7.1	0.0	0.0	0.0	8.47
1.24	9.39	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.39
1.26	9.54	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.31
1.28	9.69	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.23
1.30	9.84	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.15
1.32	9.99	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.08
1.34	10.14	32.0	32.0	32.0	7.2	0.0	0.0	0.0	8.00
1.36	10.29	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.93
1.38	10.44	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.85
1.40	10.59	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.78
1.42	10.74	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.71
1.44	10.89	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.63
1.46	11.04	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.56
1.48	11.19	32.0	32.0	32.0	7.3	0.0	0.0	0.0	7.49
1.50	11.34	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.42
1.52	11.49	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.35
1.54	11.65	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.28

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	11.80	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.22
1.58	11.95	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.15
1.60	12.10	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.08
1.62	12.25	32.0	32.0	32.0	7.4	0.0	0.0	0.0	7.02
1.64	12.40	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.95
1.66	12.55	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.89
1.68	12.70	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.82
1.70	12.86	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.76
1.72	13.01	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.70
1.74	13.16	32.0	32.0	32.0	7.5	0.0	0.0	0.0	6.63
1.76	13.31	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.57
1.78	13.46	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.51
1.80	13.62	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.45
1.82	13.77	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.39
1.84	13.92	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.33
1.86	14.07	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.27
1.88	14.23	32.0	32.0	32.0	7.6	0.0	0.0	0.0	6.22
1.90	14.38	32.0	32.0	32.0	7.7	0.0	0.0	0.0	6.16
1.92	14.53	32.0	32.0	32.0	7.7	0.0	0.0	0.0	6.10
1.94	14.69	32.0	32.0	32.0	7.7	0.0	0.0	0.0	6.04
1.96	14.84	32.0	32.0	32.0	7.7	0.0	0.0	0.0	5.99
1.98	14.99	32.0	32.0	32.0	7.7	0.0	0.0	0.0	5.93

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	1.83	3.83	0.55	4.38	3.00	0.40	0.10
0.0	0.37	67.47	2.18	69.65	31.51	101.16	4.84	27.64	92.02
0.02	0.51	63.93	2.24	66.17	30.50	96.67	5.04	27.30	85.58
0.04	0.65	60.10	2.27	62.38	29.58	91.96	5.20	26.98	79.86
0.06	0.80	56.68	2.31	58.99	28.75	87.74	5.34	26.69	74.75
0.08	0.94	53.59	2.35	55.94	27.98	83.93	5.46	26.41	70.14
0.10	1.08	50.78	2.40	53.18	27.28	80.46	5.57	26.15	65.95
0.12	1.22	48.22	2.45	50.67	26.72	77.39	5.56	25.90	62.13
0.14	1.37	45.87	2.50	48.37	26.22	74.58	5.53	25.66	58.63
0.16	1.51	43.70	2.55	46.25	25.73	71.98	5.51	25.43	55.40
0.18	1.65	41.68	2.60	44.29	25.24	69.53	5.51	25.21	52.41
0.20	1.79	39.81	2.66	42.47	24.75	67.21	5.53	25.00	49.63
0.22	1.94	38.06	2.71	40.77	24.25	65.02	5.58	24.79	47.05
0.24	2.08	36.42	2.77	39.19	23.76	62.94	5.63	24.58	44.63
0.26	2.22	34.88	2.82	37.70	23.29	60.99	5.68	24.39	42.37
0.28	2.37	33.43	2.88	36.31	22.83	59.14	5.72	24.19	40.25
0.30	2.51	32.07	2.93	35.00	22.39	57.40	5.76	24.00	38.26
0.32	2.66	30.78	2.99	33.77	21.97	55.74	5.80	23.82	36.38
0.34	2.80	29.56	3.04	32.60	21.56	54.16	5.83	23.63	34.61
0.36	2.94	28.40	3.10	31.50	21.16	52.66	5.85	23.45	32.94
0.38	3.09	27.30	3.15	30.45	20.77	51.23	5.88	23.28	31.36
0.40	3.23	26.26	3.20	29.46	20.40	49.86	5.90	23.10	29.87
0.42	3.38	25.27	3.26	28.52	20.03	48.55	5.92	22.93	28.45
0.44	3.52	24.32	3.31	27.63	19.67	47.30	5.93	22.76	27.11
0.46	3.66	23.42	3.36	26.78	19.32	46.10	5.95	22.59	25.83
0.48	3.81	22.55	3.42	25.97	18.98	44.95	5.96	22.43	24.62
0.50	3.95	21.73	3.47	25.20	18.65	43.85	5.97	22.26	23.47

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	4.10	20.95	3.52	24.46	18.32	42.78	5.97	22.10	22.38
0.54	4.24	20.19	3.57	23.76	18.00	41.76	5.98	21.94	21.34
0.56	4.39	19.47	3.62	23.09	17.69	40.78	5.98	21.78	20.35
0.58	4.53	18.78	3.67	22.45	17.38	39.83	5.98	21.62	19.41
0.60	4.68	18.12	3.72	21.84	17.08	38.92	5.98	21.47	18.52
0.62	4.83	17.49	3.76	21.25	16.79	38.04	5.98	21.32	17.67
0.64	4.97	16.88	3.81	20.70	16.50	37.20	5.97	21.16	16.85
0.66	5.12	16.30	3.86	20.16	16.22	36.38	5.97	21.01	16.08
0.68	5.26	15.74	3.91	19.65	15.94	35.59	5.96	20.86	15.34
0.70	5.41	15.20	3.95	19.16	15.67	34.82	5.95	20.71	14.64
0.72	5.55	14.69	4.00	18.69	15.40	34.09	5.94	20.57	13.97
0.74	5.70	14.19	4.04	18.23	15.14	33.37	5.93	20.42	13.33
0.76	5.85	13.71	4.09	17.80	14.88	32.69	5.92	20.28	12.72
0.78	5.99	13.26	4.13	17.39	14.63	32.02	5.91	20.13	12.14
0.80	6.14	12.82	4.18	16.99	14.38	31.37	5.89	19.99	11.59
0.82	6.29	12.39	4.22	16.61	14.14	30.75	5.87	19.85	11.06
0.84	6.43	11.98	4.26	16.25	13.93	30.18	5.82	19.71	10.56
0.86	6.58	11.59	4.30	15.89	13.76	29.65	5.76	19.57	10.08
0.88	6.73	11.21	4.35	15.56	13.60	29.16	5.67	19.43	9.62
0.90	6.87	10.85	4.39	15.23	13.47	28.71	5.59	19.30	9.18
0.92	7.02	10.53	4.44	14.97	13.35	28.31	5.50	19.17	8.80
0.94	7.17	10.25	4.51	14.76	13.22	27.98	5.43	19.05	8.48
0.96	7.32	10.00	4.58	14.58	13.09	27.67	5.37	18.94	8.18
0.98	7.46	9.75	4.65	14.40	12.97	27.37	5.30	18.83	7.90
1.00	7.61	9.51	4.72	14.23	12.85	27.08	5.24	18.73	7.63
1.02	7.76	9.28	4.79	14.07	12.73	26.80	5.18	18.62	7.36

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	7.91	9.05	4.86	13.91	12.61	26.52	5.11	18.51	7.11
1.06	8.06	8.83	4.93	13.76	12.49	26.25	5.05	18.40	6.86
1.08	8.20	8.61	4.99	13.61	12.37	25.98	4.99	18.30	6.63
1.10	8.35	8.41	5.06	13.46	12.26	25.72	4.93	18.19	6.40
1.12	8.50	8.20	5.12	13.32	12.14	25.46	4.87	18.09	6.18
1.14	8.65	8.00	5.18	13.19	12.03	25.21	4.82	17.98	5.96
1.16	8.80	7.81	5.25	13.06	11.91	24.97	4.76	17.88	5.76
1.18	8.95	7.62	5.31	12.93	11.80	24.73	4.70	17.78	5.56
1.20	9.10	7.44	5.37	12.81	11.69	24.50	4.65	17.68	5.37
1.22	9.25	7.26	5.43	12.69	11.58	24.27	4.59	17.57	5.18
1.24	9.39	7.09	5.49	12.57	11.47	24.05	4.54	17.47	5.00
1.26	9.54	6.92	5.54	12.46	11.36	23.83	4.48	17.37	4.83
1.28	9.69	6.75	5.60	12.35	11.26	23.61	4.43	17.27	4.66
1.30	9.84	6.59	5.66	12.25	11.15	23.40	4.38	17.18	4.50
1.32	9.99	6.44	5.71	12.15	11.05	23.20	4.33	17.08	4.35
1.34	10.14	6.28	5.77	12.05	10.95	23.00	4.28	16.98	4.20
1.36	10.29	6.13	5.82	11.96	10.84	22.80	4.23	16.88	4.05
1.38	10.44	5.99	5.88	11.87	10.74	22.61	4.18	16.79	3.91
1.40	10.59	5.85	5.93	11.78	10.64	22.42	4.13	16.69	3.78
1.42	10.74	5.71	5.98	11.69	10.54	22.23	4.08	16.59	3.65
1.44	10.89	5.58	6.03	11.61	10.44	22.05	4.03	16.50	3.52
1.46	11.04	5.45	6.08	11.53	10.35	21.87	3.99	16.41	3.40
1.48	11.19	5.32	6.13	11.45	10.25	21.70	3.94	16.31	3.29
1.50	11.34	5.19	6.18	11.38	10.15	21.53	3.90	16.22	3.17
1.52	11.49	5.07	6.23	11.31	10.06	21.36	3.85	16.13	3.06
1.54	11.65	4.96	6.28	11.24	9.97	21.20	3.81	16.04	2.96

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	11.80	4.84	6.33	11.17	9.87	21.04	3.76	15.94	2.86
1.58	11.95	4.73	6.38	11.10	9.78	20.88	3.72	15.85	2.76
1.60	12.10	4.62	6.42	11.04	9.69	20.73	3.68	15.76	2.66
1.62	12.25	4.51	6.47	10.98	9.60	20.58	3.63	15.67	2.57
1.64	12.40	4.41	6.51	10.92	9.51	20.43	3.59	15.59	2.48
1.66	12.55	4.31	6.56	10.87	9.42	20.29	3.55	15.50	2.40
1.68	12.70	4.21	6.60	10.81	9.33	20.14	3.51	15.41	2.31
1.70	12.86	4.11	6.65	10.76	9.25	20.01	3.47	15.32	2.24
1.72	13.01	4.02	6.69	10.71	9.16	19.87	3.43	15.24	2.16
1.74	13.16	3.92	6.74	10.66	9.08	19.74	3.39	15.15	2.08
1.76	13.31	3.83	6.78	10.61	8.99	19.60	3.35	15.06	2.01
1.78	13.46	3.75	6.82	10.57	8.91	19.48	3.32	14.98	1.94
1.80	13.62	3.66	6.86	10.52	8.83	19.35	3.28	14.89	1.88
1.82	13.77	3.58	6.90	10.48	8.74	19.23	3.24	14.81	1.81
1.84	13.92	3.50	6.95	10.44	8.66	19.11	3.21	14.73	1.75
1.86	14.07	3.42	6.99	10.40	8.58	18.99	3.17	14.64	1.69
1.88	14.23	3.34	7.03	10.37	8.50	18.87	3.13	14.56	1.63
1.90	14.38	3.26	7.07	10.33	8.42	18.76	3.10	14.48	1.58
1.92	14.53	3.19	7.11	10.30	8.35	18.64	3.06	14.40	1.52
1.94	14.69	3.12	7.15	10.26	8.27	18.53	3.03	14.32	1.47
1.96	14.84	3.05	7.19	10.23	8.19	18.43	3.00	14.24	1.42
1.98	14.99	2.98	7.22	10.20	8.12	18.32	3.00	14.16	1.37

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1970 STATUS, EXISTING PLANT, 50,000 PE, 10-YR LOW FLOW FREQ.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.57	0.37	0.0	8.34	0.37	0.0
MINIMUM DO, MG/L	0.0	7.17	0.94	0.0	7.17	0.94
FINAL DO, MG/L	2.04	6.14	0.80	1.95	6.14	0.80
DO DEFICIT						
INITIAL, MG/L	2.58	0.37	0.0	2.81	0.37	0.0
FINAL, MG/L	12.14	6.14	0.80	12.22	6.14	0.80
RIVER DISCHARGE						
INITIAL, CFS	6.26	0.37	0.0	6.26	0.37	0.0
FINAL, CFS	6.84	6.14	0.80	6.84	6.14	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	48.56	0.37	0.0	48.56	0.37	0.0
FINAL, DEG F	32.17	6.14	0.80	32.17	6.14	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	67.47	0.37	0.0	67.47	0.37	0.0
FINAL BOD, MG/L	12.73	6.14	0.80	12.90	6.14	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.17	0.37	0.0	0.17	0.37	0.0
FINAL BOD IN RIVER	4.11	6.14	0.80	4.24	6.14	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	31.51	0.37	0.0	31.51	0.37	0.0
FINAL BOD, MG/L	14.37	6.14	0.80	14.39	6.14	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	100.81	0.37	0.0	101.51	0.37	0.0
FINAL VALUE, MG/L	31.21	6.14	0.80	31.53	6.14	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	23.03	0.37	0.0	23.03	0.37	0.0
FINAL VALUE, MG/L	10.51	6.14	0.80	10.52	6.14	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.84	0.37	0.0	4.84	0.37	0.0
FINAL VALUE, MG/L	5.90	6.14	0.80	5.88	6.14	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	27.64	0.37	0.0	27.64	0.37	0.0
FINAL VALUE, MG/L	19.99	6.14	0.80	19.99	6.14	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	92.02	0.37	0.0	92.02	0.37	0.0
FINAL PERCENT	11.59	6.14	0.80	11.59	6.14	0.80

XXV. APPENDIX H

A. Computer Results for 1990 Design Level, Trickling Filter and Ames Reservoir, August, 10 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : AUGUST

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
7.19	70.00	75.00	0.0	24.00	0.080	0.0	5.00	20.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
88.00	73.00	120.00	75.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	50.00	2.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.60	105.00	60.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDO	DOFSH	K2ICE	K2R
88.00	73.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	2.00	3.00	3.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 2.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 11.13 CFS, RIVER Q = 50.00 CFS, TOTAL Q = 61.13 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 1.00 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	88.0	73.0		50.0	8.48	6.21		0.40
0.0	0.37	84.7	72.5	78.6	61.1	8.10	6.25	7.17	1.24
0.01	0.54	84.9	72.5	78.7	61.2	7.92	6.06	6.99	1.17
0.02	0.70	85.1	72.5	78.8	61.3	7.78	5.87	6.83	1.10
0.03	0.87	85.2	72.5	78.9	61.4	7.68	5.71	6.69	1.04
0.04	1.04	85.4	72.6	79.0	61.5	7.62	5.56	6.59	0.98
0.05	1.20	85.5	72.6	79.1	61.6	7.61	5.43	6.52	0.92
0.06	1.37	85.7	72.6	79.1	61.7	7.63	5.30	6.46	0.87
0.07	1.54	85.8	72.6	79.2	61.8	7.68	5.19	6.43	0.82
0.08	1.70	85.9	72.7	79.3	61.9	7.77	5.08	6.43	0.77
0.09	1.87	86.0	72.7	79.4	62.0	7.90	4.97	6.43	0.73
0.10	2.04	86.2	72.7	79.4	62.1	8.05	4.87	6.46	0.69
0.11	2.20	86.3	72.7	79.5	62.2	8.23	4.77	6.50	0.65
0.12	2.37	86.4	72.7	79.5	62.3	8.44	4.67	6.55	0.61
0.13	2.54	86.4	72.7	79.6	62.4	8.67	4.58	6.62	0.58
0.14	2.71	86.5	72.8	79.6	62.5	8.91	4.49	6.70	0.55
0.15	2.88	86.6	72.8	79.7	62.6	9.17	4.40	6.79	0.52
0.16	3.04	86.7	72.8	79.7	62.7	9.45	4.32	6.88	0.51
0.17	3.21	86.8	72.8	79.8	62.8	9.72	4.24	6.98	0.49
0.18	3.38	86.8	72.8	79.8	62.9	10.01	4.17	7.09	0.48
0.19	3.55	86.9	72.8	79.9	63.0	10.29	4.11	7.20	0.47
0.20	3.72	87.0	72.8	79.9	63.1	10.57	4.05	7.31	0.46
0.21	3.88	87.0	72.8	79.9	63.2	10.84	4.00	7.42	0.45
0.22	4.05	87.1	72.8	80.0	63.3	11.11	3.95	7.53	0.44
0.23	4.22	87.1	72.9	80.0	63.4	11.35	3.90	7.63	0.43
0.24	4.39	87.2	72.9	80.0	63.5	11.58	3.87	7.72	0.42
0.25	4.56	87.2	72.9	80.0	63.6	11.79	3.84	7.81	0.41

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	4.73	87.3	72.9	80.1	63.7	11.98	3.81	7.89	0.40
0.27	4.90	87.3	72.9	80.1	63.8	12.14	3.80	7.97	0.40
0.28	5.06	87.3	72.9	80.1	63.9	12.27	3.78	8.03	0.40
0.29	5.23	87.4	72.9	80.1	64.0	12.37	3.78	8.07	0.40
0.30	5.40	87.4	72.9	80.2	64.1	12.45	3.78	8.11	0.40
0.31	5.57	87.4	72.9	80.2	64.3	12.49	3.78	8.14	0.40
0.32	5.74	87.5	72.9	80.2	64.4	12.50	3.80	8.15	0.40
0.33	5.91	87.5	72.9	80.2	64.5	12.49	3.81	8.15	0.40
0.34	6.08	87.5	72.9	80.2	64.6	12.44	3.84	8.14	0.40
0.35	6.25	87.6	72.9	80.2	64.7	12.37	3.87	8.12	0.40
0.36	6.42	87.6	72.9	80.3	64.8	12.26	3.91	8.09	0.40
0.37	6.59	87.6	72.9	80.3	64.9	12.14	3.96	8.05	0.40
0.38	6.76	87.6	72.9	80.3	65.0	11.99	4.01	8.00	0.40
0.39	6.93	87.7	72.9	80.3	65.1	11.82	4.07	7.95	0.40
0.40	7.10	87.7	72.9	80.3	65.2	11.64	4.14	7.89	0.40
0.41	7.27	87.7	72.9	80.3	65.3	11.44	4.21	7.82	0.40
0.42	7.44	87.7	73.0	80.3	65.4	11.23	4.30	7.76	0.40
0.43	7.61	87.7	73.0	80.3	65.5	11.01	4.38	7.70	0.40
0.44	7.78	87.7	73.0	80.3	65.6	10.80	4.48	7.64	0.40
0.45	7.95	87.8	73.0	80.4	65.7	10.58	4.58	7.58	0.40
0.46	8.12	87.8	73.0	80.4	65.8	10.37	4.68	7.52	0.40
0.47	8.30	87.8	73.0	80.4	65.9	10.16	4.79	7.47	0.40
0.48	8.47	87.8	73.0	80.4	66.0	9.97	4.89	7.43	0.40
0.49	8.64	87.8	73.0	80.4	66.1	9.79	4.99	7.39	0.40
0.50	8.81	87.8	73.0	80.4	66.2	9.63	5.09	7.36	0.40
0.51	8.98	87.8	73.0	80.4	66.3	9.49	5.17	7.33	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	9.15	87.8	73.0	80.4	66.4	9.37	5.25	7.31	0.40
0.53	9.32	87.8	73.0	80.4	66.5	9.27	5.32	7.29	0.40
0.54	9.49	87.9	73.0	80.4	66.6	9.18	5.38	7.28	0.40
0.55	9.67	87.9	73.0	80.4	66.7	9.10	5.44	7.27	0.40
0.56	9.84	87.9	73.0	80.4	66.8	9.04	5.49	7.26	0.40
0.57	10.01	87.9	73.0	80.4	66.9	8.98	5.53	7.26	0.40
0.58	10.18	87.9	73.0	80.4	67.0	8.94	5.58	7.26	0.40
0.59	10.35	87.9	73.0	80.4	67.1	8.90	5.61	7.25	0.40
0.60	10.53	87.9	73.0	80.4	67.2	8.86	5.65	7.25	0.40
0.61	10.70	87.9	73.0	80.4	67.3	8.83	5.68	7.25	0.40
0.62	10.87	87.9	73.0	80.4	67.4	8.81	5.70	7.26	0.40
0.63	11.04	87.9	73.0	80.4	67.5	8.79	5.73	7.26	0.40
0.64	11.22	87.9	73.0	80.5	67.6	8.77	5.75	7.26	0.40
0.65	11.39	87.9	73.0	80.5	67.7	8.75	5.77	7.26	0.40
0.66	11.56	87.9	73.0	80.5	67.8	8.74	5.79	7.27	0.40
0.67	11.74	87.9	73.0	80.5	67.9	8.73	5.81	7.27	0.40
0.68	11.91	87.9	73.0	80.5	68.1	8.72	5.82	7.27	0.40
0.69	12.08	87.9	73.0	80.5	68.2	8.71	5.84	7.27	0.40
0.70	12.25	87.9	73.0	80.5	68.3	8.71	5.85	7.28	0.40
0.71	12.43	87.9	73.0	80.5	68.4	8.70	5.86	7.28	0.40
0.72	12.60	87.9	73.0	80.5	68.5	8.70	5.87	7.28	0.40
0.73	12.77	88.0	73.0	80.5	68.6	8.69	5.88	7.29	0.40
0.74	12.95	88.0	73.0	80.5	68.7	8.69	5.89	7.29	0.40
0.75	13.12	88.0	73.0	80.5	68.8	8.69	5.90	7.29	0.40
0.76	13.30	88.0	73.0	80.5	68.9	8.69	5.91	7.30	0.40
0.77	13.47	88.0	73.0	80.5	69.0	8.68	5.91	7.30	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	13.64	88.0	73.0	80.5	69.1	8.68	5.92	7.30	0.40
0.79	13.82	88.0	73.0	80.5	69.2	8.68	5.93	7.30	0.40
0.80	13.99	88.0	73.0	80.5	69.3	8.68	5.93	7.31	0.40
0.81	14.17	88.0	73.0	80.5	69.4	8.68	5.94	7.31	0.40
0.82	14.34	88.0	73.0	80.5	69.5	8.68	5.94	7.31	0.40
0.83	14.52	88.0	73.0	80.5	69.6	8.68	5.95	7.31	0.40
0.84	14.69	88.0	73.0	80.5	69.7	8.68	5.95	7.32	0.40
0.85	14.86	88.0	73.0	80.5	69.8	8.68	5.96	7.32	0.40
0.86	15.04	88.0	73.0	80.5	69.9	8.68	5.96	7.32	0.40
0.87	15.21	88.0	73.0	80.5	70.0	8.68	5.96	7.32	0.40
0.88	15.39	88.0	73.0	80.5	70.1	8.68	5.97	7.32	0.40
0.89	15.56	88.0	73.0	80.5	70.2	8.68	5.97	7.32	0.40
0.90	15.74	88.0	73.0	80.5	70.4	8.68	5.97	7.33	0.40
0.91	15.91	88.0	73.0	80.5	70.5	8.68	5.98	7.33	0.40
0.92	16.09	88.0	73.0	80.5	70.6	8.68	5.98	7.33	0.40
0.93	16.27	88.0	73.0	80.5	70.7	8.68	5.98	7.33	0.40
0.94	16.44	88.0	73.0	80.5	70.8	8.68	5.98	7.33	0.40
0.95	16.62	88.0	73.0	80.5	70.9	8.68	5.98	7.33	0.40
0.96	16.79	88.0	73.0	80.5	71.0	8.68	5.99	7.33	0.40
0.97	16.97	88.0	73.0	80.5	71.1	8.68	5.99	7.33	0.40
0.98	17.14	88.0	73.0	80.5	71.2	8.68	5.99	7.34	0.40
0.99	17.32	88.0	73.0	80.5	71.3	8.68	5.99	7.34	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.88	2.88	0.55	3.43	3.00	0.40	0.10
0.0	0.37	7.45	1.11	8.56	1.69	10.25	6.10	4.88	18.29
0.01	0.54	7.19	1.10	8.29	1.60	9.89	5.78	4.78	16.84
0.02	0.70	6.89	1.09	7.98	1.50	9.49	5.49	4.68	15.51
0.03	0.87	6.61	1.07	7.68	1.42	9.10	5.21	4.59	14.28
0.04	1.04	6.34	1.06	7.40	1.34	8.74	4.94	4.50	13.14
0.05	1.20	6.09	1.05	7.13	1.26	8.39	4.68	4.40	12.10
0.06	1.37	5.84	1.04	6.88	1.19	8.07	4.44	4.31	11.14
0.07	1.54	5.61	1.03	6.64	1.12	7.76	4.22	4.22	10.26
0.08	1.70	5.39	1.02	6.41	1.06	7.46	4.00	4.14	9.45
0.09	1.87	5.18	1.01	6.19	1.00	7.18	3.79	4.05	8.70
0.10	2.04	4.98	1.00	5.98	0.94	6.92	3.60	3.97	8.01
0.11	2.20	4.78	0.99	5.78	0.89	6.66	3.48	3.89	7.38
0.12	2.37	4.60	0.99	5.59	0.84	6.42	3.41	3.81	6.79
0.13	2.54	4.43	0.98	5.41	0.79	6.20	3.33	3.73	6.26
0.14	2.71	4.26	0.97	5.23	0.75	5.98	3.26	3.65	5.77
0.15	2.88	4.10	0.97	5.07	0.70	5.77	3.19	3.57	5.31
0.16	3.04	3.95	0.96	4.91	0.67	5.58	3.13	3.50	4.90
0.17	3.21	3.80	0.96	4.76	0.63	5.39	3.07	3.43	4.51
0.18	3.38	3.66	0.96	4.62	0.59	5.21	3.01	3.36	4.16
0.19	3.55	3.53	0.95	4.48	0.56	5.05	3.00	3.29	3.83
0.20	3.72	3.40	0.95	4.35	0.53	4.88	3.00	3.22	3.54
0.21	3.88	3.29	0.95	4.23	0.50	4.73	3.00	3.15	3.26
0.22	4.05	3.16	0.95	4.11	0.48	4.59	3.00	3.09	3.01
0.23	4.22	3.05	0.95	4.00	0.45	4.45	3.00	3.02	2.78
0.24	4.39	2.94	0.95	3.89	0.43	4.32	3.00	2.96	2.56
0.25	4.56	2.84	0.95	3.79	0.40	4.19	3.00	2.90	2.36

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	4.73	2.74	0.95	3.69	0.38	4.07	3.00	2.84	2.18
0.27	4.90	2.65	0.95	3.59	0.36	3.96	3.00	2.78	2.02
0.28	5.06	2.56	0.95	3.50	0.34	3.85	3.00	2.72	1.86
0.29	5.23	2.47	0.95	3.42	0.33	3.74	3.00	2.67	1.72
0.30	5.40	2.39	0.95	3.33	0.31	3.64	3.00	2.61	1.59
0.31	5.57	2.31	0.95	3.25	0.29	3.55	3.00	2.56	1.47
0.32	5.74	2.23	0.95	3.18	0.28	3.46	3.00	2.51	1.36
0.33	5.91	2.15	0.95	3.11	0.26	3.37	3.00	2.45	1.26
0.34	6.08	2.08	0.95	3.04	0.25	3.29	3.00	2.40	1.16
0.35	6.25	2.01	0.96	2.97	0.24	3.21	3.00	2.36	1.07
0.36	6.42	1.95	0.96	2.91	0.23	3.13	3.00	2.31	0.99
0.37	6.59	1.89	0.96	2.85	0.22	3.06	3.00	2.26	0.92
0.38	6.76	1.82	0.96	2.79	0.21	2.99	3.00	2.21	0.85
0.39	6.93	1.77	0.97	2.73	0.20	2.93	3.00	2.17	0.79
0.40	7.10	1.71	0.97	2.68	0.19	2.87	3.00	2.13	0.73
0.41	7.27	1.65	0.97	2.63	0.18	2.81	3.00	2.08	0.68
0.42	7.44	1.60	0.98	2.58	0.17	2.75	3.00	2.04	0.63
0.43	7.61	1.55	0.98	2.53	0.16	2.69	3.00	2.00	0.58
0.44	7.78	1.50	0.98	2.49	0.15	2.64	3.00	1.96	0.54
0.45	7.95	1.46	0.99	2.44	0.15	2.59	3.00	1.92	0.50
0.46	8.12	1.41	0.99	2.40	0.14	2.54	3.00	1.88	0.46
0.47	8.30	1.37	1.00	2.36	0.13	2.50	3.00	1.84	0.43
0.48	8.47	1.32	1.00	2.32	0.13	2.45	3.00	1.81	0.40
0.49	8.64	1.28	1.00	2.29	0.12	2.41	3.00	1.77	0.37
0.50	8.81	1.24	1.01	2.25	0.12	2.37	3.00	1.73	0.34
0.51	8.98	1.21	1.01	2.22	0.11	2.33	3.00	1.70	0.32

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	9.15	1.17	1.02	2.19	0.11	2.30	3.00	1.67	0.30
0.53	9.32	1.13	1.02	2.16	0.10	2.26	3.00	1.63	0.28
0.54	9.49	1.10	1.03	2.13	0.10	2.23	3.00	1.60	0.27
0.55	9.67	1.07	1.03	2.10	0.09	2.19	3.00	1.57	0.25
0.56	9.84	1.04	1.04	2.07	0.09	2.16	3.00	1.54	0.24
0.57	10.01	1.00	1.04	2.05	0.09	2.13	3.00	1.51	0.23
0.58	10.18	0.97	1.05	2.02	0.08	2.11	3.00	1.48	0.21
0.59	10.35	0.95	1.05	2.00	0.08	2.08	3.00	1.45	0.20
0.60	10.53	0.92	1.06	1.98	0.08	2.05	3.00	1.42	0.19
0.61	10.70	0.89	1.06	1.95	0.07	2.03	3.00	1.39	0.18
0.62	10.87	0.86	1.07	1.93	0.07	2.00	3.00	1.37	0.17
0.63	11.04	0.84	1.07	1.91	0.07	1.98	3.00	1.34	0.17
0.64	11.22	0.81	1.08	1.89	0.07	1.96	3.00	1.31	0.16
0.65	11.39	0.79	1.08	1.88	0.06	1.94	3.00	1.29	0.15
0.66	11.56	0.77	1.09	1.86	0.06	1.92	3.00	1.26	0.14
0.67	11.74	0.75	1.10	1.84	0.06	1.90	3.00	1.24	0.14
0.68	11.91	0.72	1.10	1.83	0.06	1.88	3.00	1.22	0.13
0.69	12.08	0.70	1.11	1.81	0.06	1.86	3.00	1.19	0.13
0.70	12.25	0.68	1.11	1.80	0.05	1.85	3.00	1.17	0.12
0.71	12.43	0.66	1.12	1.78	0.05	1.83	3.00	1.15	0.12
0.72	12.60	0.64	1.12	1.77	0.05	1.82	3.00	1.13	0.11
0.73	12.77	0.63	1.13	1.75	0.05	1.80	3.00	1.10	0.11
0.74	12.95	0.61	1.13	1.74	0.05	1.79	3.00	1.08	0.10
0.75	13.12	0.59	1.14	1.73	0.04	1.78	3.00	1.06	0.10
0.76	13.30	0.57	1.15	1.72	0.04	1.76	3.00	1.04	0.10
0.77	13.47	0.56	1.15	1.71	0.04	1.75	3.00	1.02	0.10

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

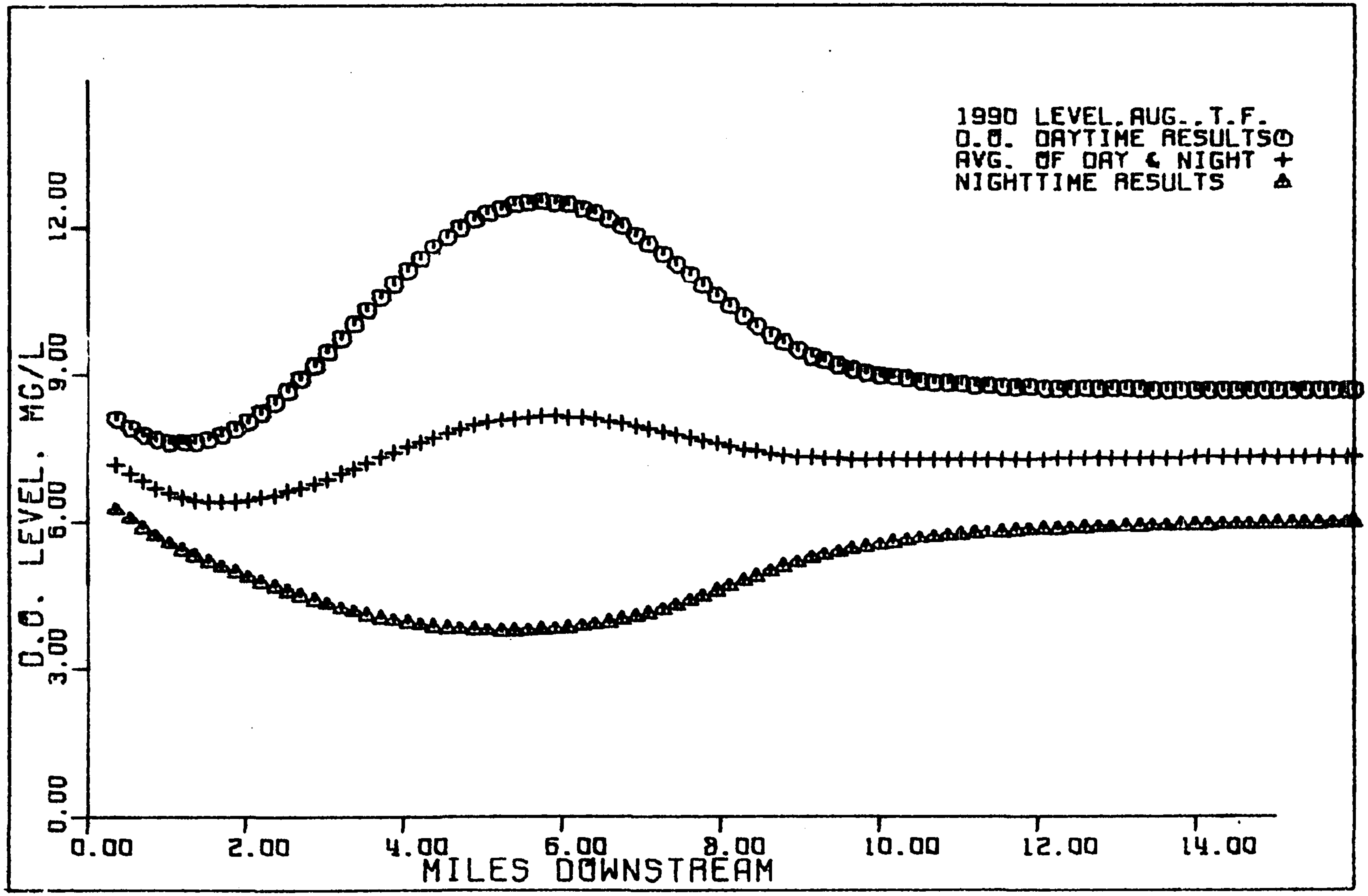
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	13.64	0.54	1.16	1.70	0.04	1.74	3.00	1.00	0.10
0.79	13.82	0.53	1.16	1.69	0.04	1.73	3.00	0.99	0.10
0.80	13.99	0.51	1.17	1.68	0.04	1.72	3.00	0.97	0.10
0.81	14.17	0.50	1.17	1.67	0.04	1.71	3.00	0.95	0.10
0.82	14.34	0.48	1.18	1.66	0.04	1.70	3.00	0.93	0.10
0.83	14.52	0.47	1.18	1.66	0.04	1.69	3.00	0.91	0.10
0.84	14.69	0.46	1.19	1.65	0.03	1.68	3.00	0.90	0.10
0.85	14.86	0.44	1.20	1.64	0.03	1.67	3.00	0.88	0.10
0.86	15.04	0.43	1.20	1.63	0.03	1.67	3.00	0.87	0.10
0.87	15.21	0.42	1.21	1.63	0.03	1.66	3.00	0.85	0.10
0.88	15.39	0.41	1.21	1.62	0.03	1.65	3.00	0.83	0.10
0.89	15.56	0.40	1.22	1.62	0.03	1.65	3.00	0.82	0.10
0.90	15.74	0.39	1.22	1.61	0.03	1.64	3.00	0.80	0.10
0.91	15.91	0.38	1.23	1.61	0.03	1.63	3.00	0.79	0.10
0.92	16.09	0.37	1.24	1.60	0.03	1.63	3.00	0.78	0.10
0.93	16.27	0.36	1.24	1.60	0.03	1.62	3.00	0.77	0.10
0.94	16.44	0.35	1.25	1.59	0.03	1.62	3.00	0.77	0.10
0.95	16.62	0.34	1.25	1.59	0.03	1.61	3.00	0.76	0.10
0.96	16.79	0.33	1.26	1.58	0.03	1.61	3.00	0.75	0.10
0.97	16.97	0.32	1.26	1.58	0.03	1.61	3.00	0.74	0.10
0.98	17.14	0.31	1.27	1.58	0.02	1.60	3.00	0.73	0.10
0.99	17.32	0.30	1.27	1.57	0.02	1.60	3.00	0.72	0.10

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

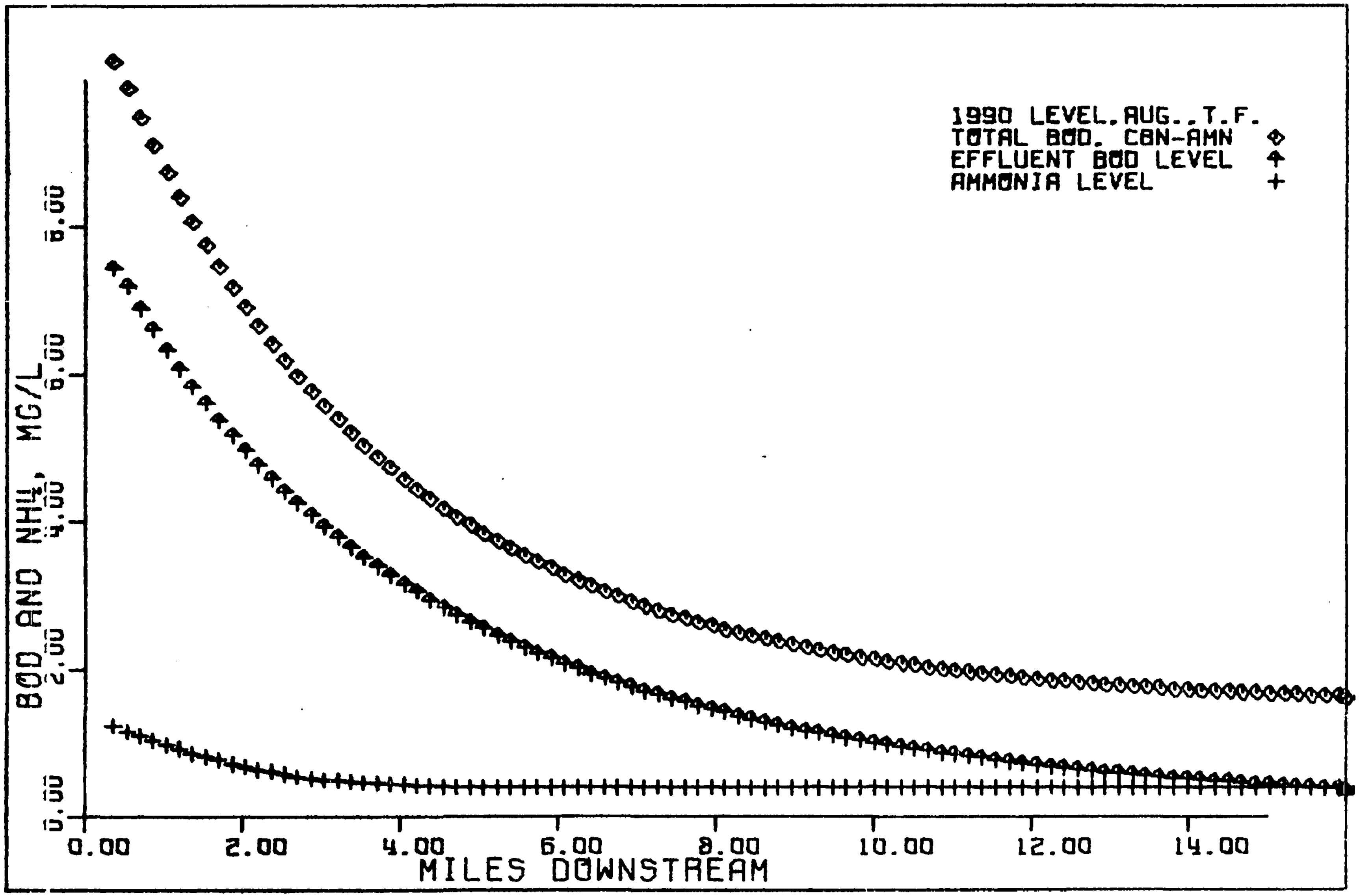
STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.10	0.37	0.0	6.25	0.37	0.0
MINIMUM DO, MG/L	7.61	1.20	0.05	3.78	5.40	0.30
FINAL DO, MG/L	8.68	13.99	0.80	5.93	13.99	0.80
DO DEFICIT						
INITIAL, MG/L	-0.79	0.37	0.0	2.08	0.37	0.0
FINAL, MG/L	-1.61	13.99	0.80	2.35	13.99	0.80
RIVER DISCHARGE						
INITIAL, CFS	61.13	0.37	0.0	61.13	0.37	0.0
FINAL, CFS	69.30	13.99	0.80	69.30	13.99	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	84.72	0.37	0.0	72.45	0.37	0.0
FINAL, DEG F	87.97	13.99	0.80	72.99	13.99	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	7.45	0.37	0.0	7.45	0.37	0.0
FINAL BOD, MG/L	0.32	13.99	0.80	0.70	13.99	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.03	0.37	0.0	0.03	0.37	0.0
FINAL BOD IN RIVER	1.02	13.99	0.80	1.31	13.99	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	1.69	0.37	0.0	1.69	0.37	0.0
FINAL BOD, MG/L	0.01	13.99	0.80	0.06	13.99	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	10.02	0.37	0.0	10.47	0.37	0.0
FINAL VALUE, MG/L	1.36	13.99	0.80	2.08	13.99	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	1.24	0.37	0.0	1.24	0.37	0.0
FINAL VALUE, MG/L	0.40	13.99	0.80	0.40	13.99	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	6.10	0.37	0.0	6.10	0.37	0.0
FINAL VALUE, MG/L	3.00	13.99	0.80	3.00	13.99	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.88	0.37	0.0	4.88	0.37	0.0
FINAL VALUE, MG/L	0.53	13.99	0.80	1.40	13.99	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	18.29	0.37	0.0	18.29	0.37	0.0
FINAL PERCENT	0.10	13.99	0.80	0.10	13.99	0.80



1990 LEVEL.AUG..T.F.
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


1990 LEVEL, AUG., T.F.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
2.00
4.00
6.00
8.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

B. Computer Results for 1990 Design Level,

Trickling Filter and Ames Reservoir, September, 10 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : SEPT.

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
7.19	65.00	75.00	0.0	24.00	0.080	0.0	10.00	15.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
83.00	68.00	125.00	70.00	2.50	0.140	0.0	0.40	3.00	0.40	0.10	60.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.30	110.00	55.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
83.00	68.00	2.500	0.0	0.0	3.000	0.100	0.40	1.20	1.60	2.50	2.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 60.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 3.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 11.13 CFS, RIVER Q = 50.00 CFS, TOTAL Q = 61.13 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 1.20 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	83.0	68.0		50.0	9.31	6.13		0.40
0.0	0.37	79.7	67.5	73.6	61.1	8.85	6.25	7.55	2.15
0.01	0.54	79.9	67.5	73.7	61.2	8.60	5.81	7.21	2.05
0.02	0.70	80.1	67.5	73.8	61.2	8.40	5.40	6.90	1.95
0.03	0.87	80.2	67.5	73.9	61.3	8.25	5.03	6.64	1.86
0.04	1.04	80.4	67.6	74.0	61.3	8.14	4.71	6.42	1.78
0.05	1.20	80.5	67.6	74.1	61.4	8.08	4.41	6.25	1.70
0.06	1.37	80.7	67.6	74.1	61.4	8.05	4.15	6.10	1.62
0.07	1.54	80.8	67.6	74.2	61.5	8.07	3.91	5.99	1.54
0.08	1.70	80.9	67.7	74.3	61.5	8.12	3.68	5.90	1.47
0.09	1.87	81.0	67.7	74.4	61.6	8.21	3.47	5.84	1.40
0.10	2.04	81.2	67.7	74.4	61.6	8.33	3.28	5.80	1.34
0.11	2.20	81.3	67.7	74.5	61.7	8.47	3.10	5.79	1.28
0.12	2.37	81.4	67.7	74.5	61.7	8.65	2.94	5.79	1.22
0.13	2.54	81.4	67.7	74.6	61.8	8.85	2.78	5.82	1.16
0.14	2.70	81.5	67.8	74.6	61.8	9.07	2.64	5.86	1.11
0.15	2.87	81.6	67.9	74.7	61.9	9.32	2.50	5.91	1.06
0.16	3.04	81.7	67.8	74.7	61.9	9.58	2.37	5.98	1.01
0.17	3.20	81.8	67.8	74.8	62.0	9.86	2.26	6.06	0.96
0.18	3.37	81.8	67.8	74.8	62.0	10.14	2.15	6.15	0.92
0.19	3.54	81.9	67.8	74.9	62.1	10.44	2.05	6.25	0.88
0.20	3.71	82.0	67.8	74.9	62.1	10.74	1.96	6.35	0.84
0.21	3.87	82.0	67.8	74.9	62.2	11.05	1.88	6.47	0.80
0.22	4.04	82.1	67.8	75.0	62.2	11.36	1.81	6.58	0.77
0.23	4.21	82.1	67.9	75.0	62.3	11.66	1.75	6.70	0.73
0.24	4.38	82.2	67.9	75.0	62.3	11.96	1.69	6.83	0.70
0.25	4.54	82.2	67.9	75.0	62.4	12.25	1.65	6.95	0.67

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	4.71	82.3	67.9	75.1	62.4	12.53	1.60	7.07	0.64
0.27	4.88	82.3	67.9	75.1	62.5	12.80	1.57	7.18	0.62
0.28	5.05	82.3	67.9	75.1	62.5	13.05	1.54	7.30	0.61
0.29	5.21	82.4	67.9	75.1	62.6	13.29	1.51	7.40	0.60
0.30	5.38	82.4	67.9	75.2	62.6	13.50	1.50	7.50	0.59
0.31	5.55	82.4	67.9	75.2	62.7	13.69	1.48	7.59	0.57
0.32	5.72	82.5	67.9	75.2	62.7	13.86	1.47	7.67	0.56
0.33	5.88	82.5	67.9	75.2	62.8	14.01	1.46	7.74	0.55
0.34	6.05	82.5	67.9	75.2	62.8	14.13	1.46	7.80	0.54
0.35	6.22	82.6	67.9	75.2	62.9	14.22	1.46	7.84	0.53
0.36	6.39	82.6	67.9	75.3	62.9	14.29	1.47	7.88	0.52
0.37	6.56	82.6	67.9	75.3	63.0	14.33	1.48	7.90	0.51
0.38	6.73	82.6	67.9	75.3	63.0	14.34	1.49	7.92	0.51
0.39	6.89	82.7	67.9	75.3	63.1	14.33	1.51	7.92	0.50
0.40	7.06	82.7	67.9	75.3	63.1	14.29	1.53	7.91	0.49
0.41	7.23	82.7	67.9	75.3	63.2	14.22	1.55	7.89	0.48
0.42	7.40	82.7	68.0	75.3	63.2	14.13	1.58	7.86	0.47
0.43	7.57	82.7	68.0	75.3	63.3	14.01	1.62	7.82	0.46
0.44	7.74	82.7	68.0	75.3	63.3	13.88	1.66	7.77	0.46
0.45	7.90	82.8	68.0	75.4	63.4	13.72	1.70	7.71	0.45
0.46	8.07	82.8	68.0	75.4	63.4	13.55	1.75	7.65	0.44
0.47	8.24	82.8	68.0	75.4	63.5	13.36	1.80	7.58	0.43
0.48	8.41	82.8	68.0	75.4	63.5	13.15	1.86	7.51	0.42
0.49	8.58	82.8	68.0	75.4	63.6	12.94	1.93	7.43	0.42
0.50	8.75	82.8	68.0	75.4	63.6	12.71	2.00	7.36	0.41
0.51	8.92	82.8	68.0	75.4	63.7	12.48	2.08	7.28	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	9.09	82.8	68.0	75.4	63.7	12.25	2.16	7.21	0.40
0.53	9.25	82.8	68.0	75.4	63.8	12.02	2.25	7.13	0.40
0.54	9.42	82.9	68.0	75.4	63.8	11.79	2.35	7.07	0.40
0.55	9.59	82.9	68.0	75.4	63.9	11.56	2.45	7.00	0.40
0.56	9.76	82.9	68.0	75.4	63.9	11.34	2.55	6.95	0.40
0.57	9.93	82.9	68.0	75.4	64.0	11.13	2.66	6.90	0.40
0.58	10.10	82.9	68.0	75.4	64.0	10.94	2.76	6.85	0.40
0.59	10.27	82.9	68.0	75.4	64.1	10.75	2.87	6.81	0.40
0.60	10.44	82.9	68.0	75.4	64.1	10.59	2.97	6.78	0.40
0.61	10.61	82.9	68.0	75.4	64.2	10.44	3.06	6.75	0.40
0.62	10.78	82.9	68.0	75.4	64.3	10.32	3.14	6.73	0.40
0.63	10.95	82.9	68.0	75.4	64.3	10.21	3.22	6.71	0.40
0.64	11.12	82.9	68.0	75.5	64.4	10.11	3.29	6.70	0.40
0.65	11.29	82.9	68.0	75.5	64.4	10.03	3.35	6.69	0.40
0.66	11.45	82.9	68.0	75.5	64.5	9.96	3.40	6.68	0.40
0.67	11.62	82.9	68.0	75.5	64.5	9.89	3.45	6.67	0.40
0.68	11.79	82.9	68.0	75.5	64.6	9.84	3.50	6.67	0.40
0.69	11.96	82.9	68.0	75.5	64.6	9.80	3.54	6.67	0.40
0.70	12.13	82.9	68.0	75.5	64.7	9.76	3.58	6.67	0.40
0.71	12.30	82.9	68.0	75.5	64.7	9.72	3.62	6.67	0.40
0.72	12.47	82.9	68.0	75.5	64.8	9.69	3.65	6.67	0.40
0.73	12.64	83.0	68.0	75.5	64.8	9.67	3.68	6.67	0.40
0.74	12.81	83.0	68.0	75.5	64.9	9.65	3.70	6.68	0.40
0.75	12.98	83.0	68.0	75.5	64.9	9.63	3.73	6.68	0.40
0.76	13.15	83.0	68.0	75.5	65.0	9.61	3.75	6.68	0.40
0.77	13.32	83.0	68.0	75.5	65.0	9.60	3.77	6.69	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	13.49	83.0	68.0	75.5	65.1	9.59	3.79	6.69	0.40
0.79	13.66	83.0	68.0	75.5	65.1	9.58	3.81	6.69	0.40
0.80	13.83	83.0	68.0	75.5	65.2	9.57	3.83	6.70	0.40
0.81	14.00	83.0	68.0	75.5	65.2	9.56	3.84	6.70	0.40
0.82	14.17	83.0	68.0	75.5	65.3	9.55	3.85	6.70	0.40
0.83	14.35	83.0	68.0	75.5	65.3	9.55	3.87	6.71	0.40
0.84	14.52	83.0	68.0	75.5	65.4	9.54	3.88	6.71	0.40
0.85	14.69	83.0	68.0	75.5	65.4	9.54	3.89	6.72	0.40
0.86	14.86	83.0	68.0	75.5	65.5	9.54	3.90	6.72	0.40
0.87	15.03	83.0	68.0	75.5	65.5	9.53	3.91	6.72	0.40
0.88	15.20	83.0	68.0	75.5	65.6	9.53	3.92	6.73	0.40
0.89	15.37	83.0	68.0	75.5	65.6	9.53	3.93	6.73	0.40
0.90	15.54	83.0	68.0	75.5	65.7	9.53	3.93	6.73	0.40
0.91	15.71	83.0	68.0	75.5	65.7	9.53	3.94	6.74	0.40
0.92	15.88	83.0	68.0	75.5	65.8	9.53	3.95	6.74	0.40
0.93	16.05	83.0	68.0	75.5	65.8	9.53	3.96	6.74	0.40
0.94	16.22	83.0	68.0	75.5	65.9	9.53	3.96	6.74	0.40
0.95	16.39	83.0	68.0	75.5	65.9	9.53	3.97	6.75	0.40
0.96	16.57	83.0	68.0	75.5	66.0	9.52	3.97	6.75	0.40
0.97	16.74	83.0	68.0	75.5	66.0	9.52	3.98	6.75	0.40
0.98	16.91	83.0	68.0	75.5	66.1	9.52	3.98	6.75	0.40
0.99	17.08	83.0	68.0	75.5	66.1	9.52	3.99	6.76	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.50	1.02	3.51	0.55	4.06	3.00	0.40	0.10
0.0	0.37	7.86	1.26	9.11	2.94	12.05	5.18	4.88	18.29
0.01	0.54	7.61	1.25	8.86	2.80	11.67	5.00	4.80	17.03
0.02	0.70	7.33	1.24	8.57	2.67	11.24	4.81	4.73	15.86
0.03	0.87	7.06	1.23	8.28	2.55	10.84	4.64	4.65	14.77
0.04	1.04	6.80	1.21	8.01	2.43	10.45	4.47	4.58	13.76
0.05	1.20	6.55	1.20	7.76	2.32	10.08	4.30	4.50	12.81
0.06	1.37	6.32	1.19	7.51	2.21	9.72	4.14	4.43	11.93
0.07	1.54	6.09	1.19	7.28	2.11	9.39	3.99	4.36	11.11
0.08	1.70	5.87	1.18	7.05	2.01	9.06	3.84	4.29	10.34
0.09	1.87	5.67	1.17	6.83	1.92	8.76	3.70	4.22	9.63
0.10	2.04	5.47	1.16	6.63	1.83	8.46	3.56	4.15	8.97
0.11	2.20	5.28	1.16	6.43	1.75	8.18	3.43	4.08	8.35
0.12	2.37	5.09	1.15	6.24	1.67	7.91	3.36	4.01	7.78
0.13	2.54	4.92	1.15	6.06	1.59	7.65	3.31	3.95	7.25
0.14	2.70	4.75	1.14	5.89	1.52	7.41	3.26	3.88	6.75
0.15	2.87	4.59	1.14	5.73	1.45	7.17	3.21	3.82	6.29
0.16	3.04	4.43	1.14	5.57	1.38	6.95	3.16	3.76	5.86
0.17	3.20	4.28	1.13	5.42	1.32	6.74	3.11	3.70	5.46
0.18	3.37	4.14	1.13	5.27	1.26	6.53	3.07	3.64	5.08
0.19	3.54	4.00	1.13	5.14	1.20	6.34	3.02	3.58	4.74
0.20	3.71	3.87	1.13	5.00	1.15	6.15	3.00	3.52	4.42
0.21	3.87	3.75	1.13	4.88	1.10	5.97	3.00	3.46	4.12
0.22	4.04	3.62	1.13	4.75	1.05	5.80	3.00	3.40	3.84
0.23	4.21	3.51	1.13	4.64	1.00	5.64	3.00	3.35	3.58
0.24	4.38	3.39	1.13	4.53	0.96	5.49	3.00	3.29	3.33
0.25	4.54	3.29	1.13	4.42	0.92	5.34	3.00	3.24	3.11

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	4.71	3.18	1.13	4.32	0.88	5.20	3.00	3.18	2.90
0.27	4.88	3.08	1.14	4.22	0.84	5.06	3.00	3.13	2.71
0.28	5.05	2.99	1.14	4.12	0.81	4.93	3.00	3.08	2.52
0.29	5.21	2.89	1.14	4.03	0.78	4.81	3.00	3.03	2.36
0.30	5.38	2.80	1.14	3.95	0.75	4.69	3.00	2.98	2.20
0.31	5.55	2.72	1.15	3.86	0.72	4.58	3.00	2.93	2.05
0.32	5.72	2.63	1.15	3.79	0.69	4.47	3.00	2.88	1.92
0.33	5.88	2.55	1.16	3.71	0.66	4.37	3.00	2.83	1.79
0.34	6.05	2.48	1.16	3.64	0.64	4.27	3.00	2.79	1.67
0.35	6.22	2.40	1.16	3.57	0.61	4.18	3.00	2.74	1.56
0.36	6.39	2.33	1.17	3.50	0.59	4.09	3.00	2.70	1.46
0.37	6.56	2.26	1.17	3.43	0.57	4.00	3.00	2.65	1.36
0.38	6.73	2.19	1.18	3.37	0.55	3.92	3.00	2.61	1.27
0.39	6.89	2.13	1.18	3.31	0.53	3.84	3.00	2.57	1.19
0.40	7.06	2.07	1.19	3.26	0.51	3.76	3.00	2.53	1.11
0.41	7.23	2.01	1.20	3.20	0.49	3.69	3.00	2.49	1.04
0.42	7.40	1.95	1.20	3.15	0.47	3.62	3.00	2.44	0.97
0.43	7.57	1.89	1.21	3.10	0.45	3.55	3.00	2.41	0.91
0.44	7.74	1.84	1.21	3.05	0.44	3.49	3.00	2.37	0.85
0.45	7.90	1.78	1.22	3.00	0.42	3.42	3.00	2.33	0.80
0.46	8.07	1.73	1.23	2.96	0.40	3.36	3.00	2.29	0.74
0.47	8.24	1.68	1.23	2.92	0.39	3.31	3.00	2.25	0.70
0.48	8.41	1.64	1.24	2.88	0.37	3.25	3.00	2.22	0.65
0.49	8.58	1.59	1.25	2.84	0.36	3.20	3.00	2.18	0.61
0.50	8.75	1.54	1.26	2.80	0.35	3.15	3.00	2.15	0.57
0.51	8.92	1.50	1.26	2.76	0.33	3.10	3.00	2.11	0.53

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	9.09	1.46	1.27	2.73	0.32	3.05	3.00	2.08	0.50
0.53	9.25	1.42	1.28	2.70	0.31	3.01	3.00	2.05	0.47
0.54	9.42	1.38	1.29	2.67	0.30	2.96	3.00	2.01	0.44
0.55	9.59	1.34	1.29	2.64	0.28	2.92	3.00	1.98	0.41
0.56	9.76	1.30	1.30	2.61	0.27	2.88	3.00	1.95	0.39
0.57	9.93	1.27	1.31	2.58	0.26	2.84	3.00	1.92	0.36
0.58	10.10	1.23	1.32	2.55	0.25	2.81	3.00	1.89	0.34
0.59	10.27	1.20	1.33	2.53	0.24	2.77	3.00	1.86	0.32
0.60	10.44	1.17	1.34	2.50	0.23	2.74	3.00	1.83	0.30
0.61	10.61	1.14	1.34	2.48	0.23	2.71	3.00	1.80	0.29
0.62	10.78	1.11	1.35	2.46	0.22	2.68	3.00	1.77	0.27
0.63	10.95	1.08	1.36	2.44	0.21	2.65	3.00	1.74	0.26
0.64	11.12	1.05	1.37	2.42	0.20	2.62	3.00	1.72	0.25
0.65	11.29	1.02	1.38	2.40	0.19	2.59	3.00	1.69	0.24
0.66	11.45	0.99	1.39	2.38	0.19	2.57	3.00	1.66	0.23
0.67	11.62	0.97	1.40	2.36	0.18	2.54	3.00	1.64	0.22
0.68	11.79	0.94	1.41	2.35	0.17	2.52	3.00	1.61	0.21
0.69	11.96	0.91	1.41	2.33	0.17	2.50	3.00	1.59	0.20
0.70	12.13	0.89	1.42	2.31	0.16	2.48	3.00	1.56	0.19
0.71	12.30	0.87	1.43	2.30	0.16	2.45	3.00	1.54	0.18
0.72	12.47	0.84	1.44	2.29	0.15	2.44	3.00	1.51	0.17
0.73	12.64	0.82	1.45	2.27	0.14	2.42	3.00	1.49	0.17
0.74	12.81	0.80	1.46	2.26	0.14	2.40	3.00	1.47	0.16
0.75	12.98	0.78	1.47	2.25	0.13	2.38	3.00	1.44	0.15
0.76	13.15	0.76	1.48	2.24	0.13	2.37	3.00	1.42	0.15
0.77	13.32	0.74	1.49	2.23	0.12	2.35	3.00	1.40	0.14

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

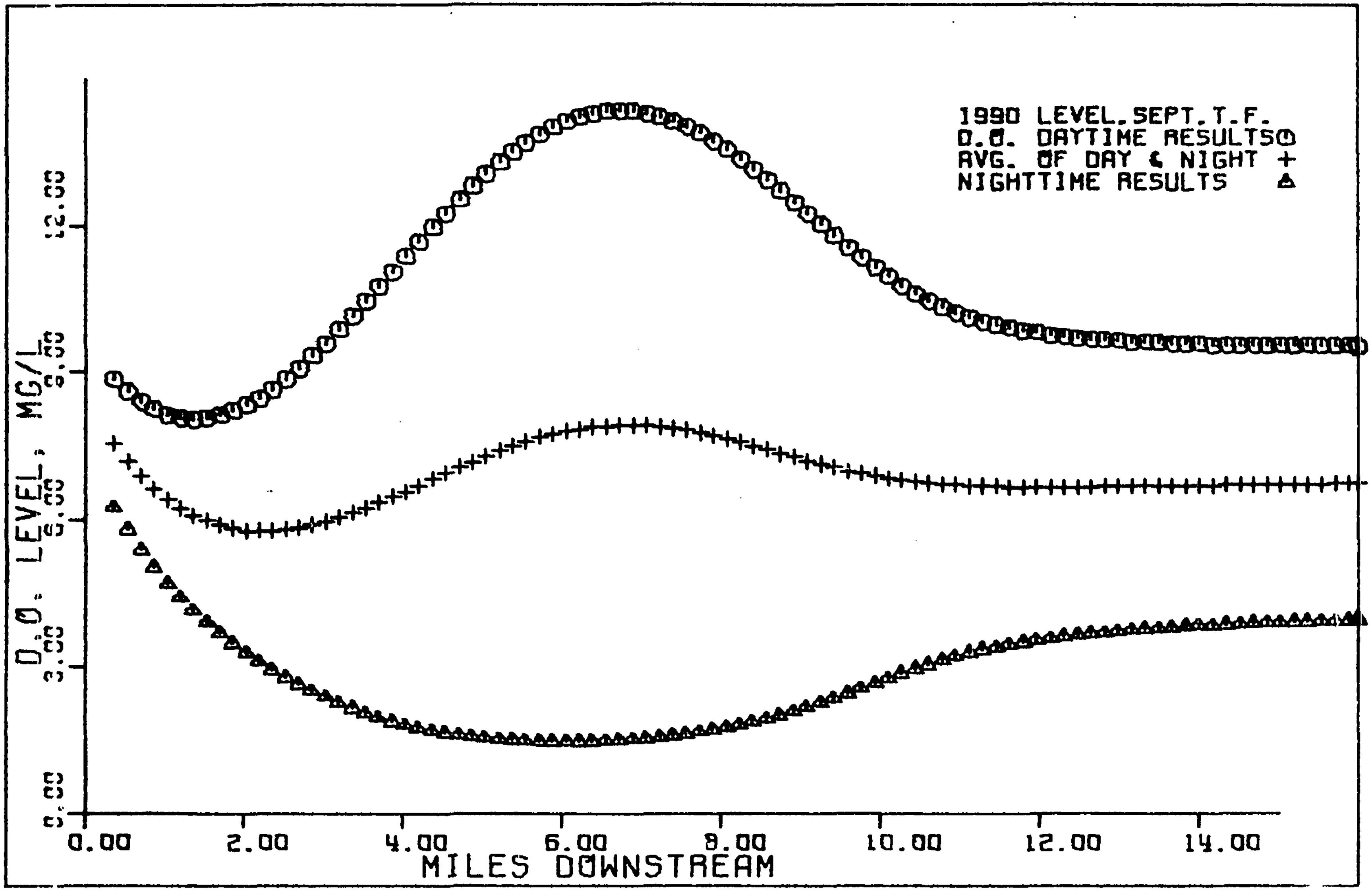
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	13.49	0.72	1.50	2.22	0.12	2.34	3.00	1.38	0.14
0.79	13.66	0.70	1.51	2.21	0.12	2.32	3.00	1.36	0.13
0.80	13.83	0.68	1.52	2.20	0.11	2.31	3.00	1.34	0.13
0.81	14.00	0.67	1.53	2.19	0.11	2.30	3.00	1.32	0.12
0.82	14.17	0.65	1.54	2.18	0.10	2.29	3.00	1.30	0.12
0.83	14.35	0.63	1.54	2.18	0.10	2.28	3.00	1.28	0.11
0.84	14.52	0.62	1.55	2.17	0.10	2.27	3.00	1.26	0.11
0.85	14.69	0.60	1.56	2.16	0.09	2.26	3.00	1.24	0.11
0.86	14.86	0.58	1.57	2.16	0.09	2.25	3.00	1.22	0.10
0.87	15.03	0.57	1.58	2.15	0.09	2.24	3.00	1.20	0.10
0.88	15.20	0.55	1.59	2.15	0.09	2.23	3.00	1.18	0.10
0.89	15.37	0.54	1.60	2.14	0.08	2.22	3.00	1.17	0.10
0.90	15.54	0.53	1.61	2.14	0.08	2.22	3.00	1.15	0.10
0.91	15.71	0.51	1.62	2.13	0.08	2.21	3.00	1.13	0.10
0.92	15.88	0.50	1.63	2.13	0.07	2.20	3.00	1.11	0.10
0.93	16.05	0.49	1.64	2.13	0.07	2.20	3.00	1.10	0.10
0.94	16.22	0.47	1.65	2.12	0.07	2.19	3.00	1.08	0.10
0.95	16.39	0.46	1.66	2.12	0.07	2.19	3.00	1.06	0.10
0.96	16.57	0.45	1.67	2.12	0.07	2.18	3.00	1.05	0.10
0.97	16.74	0.44	1.68	2.12	0.06	2.18	3.00	1.03	0.10
0.98	16.91	0.43	1.69	2.11	0.06	2.18	3.00	1.02	0.10
0.99	17.08	0.42	1.69	2.11	0.06	2.17	3.00	1.00	0.10

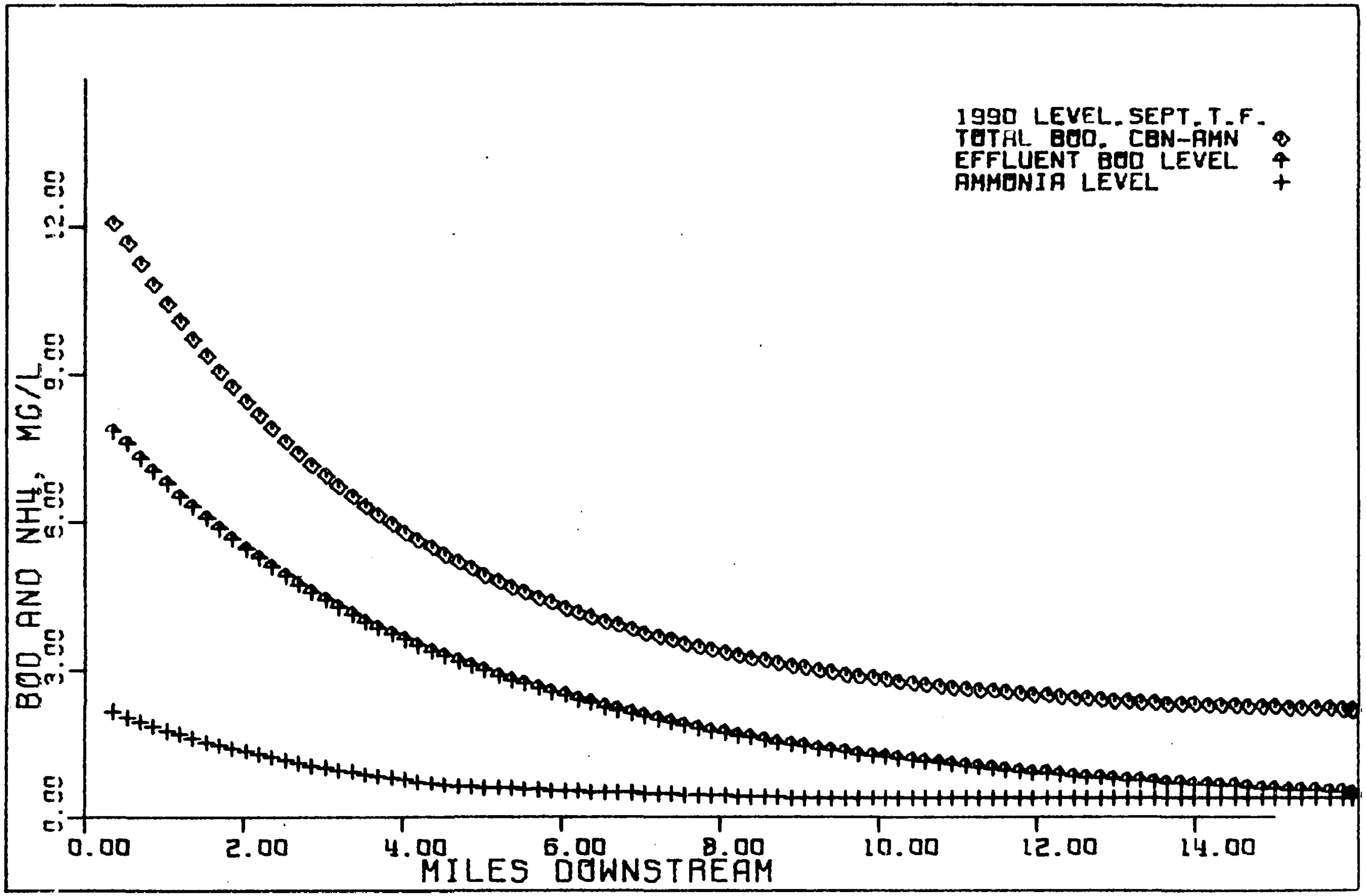
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.85	0.37	0.0	6.25	0.37	0.0
MINIMUM DO, MG/L	8.05	1.37	0.06	1.46	6.05	0.34
FINAL DO, MG/L	9.57	13.83	0.80	3.83	13.83	0.80
DO DEFICIT						
INITIAL, MG/L	-1.14	0.37	0.0	2.56	0.37	0.0
FINAL, MG/L	-2.12	13.83	0.80	4.93	13.83	0.80
RIVER DISCHARGE						
INITIAL, CFS	61.13	0.37	0.0	61.13	0.37	0.0
FINAL, CFS	65.17	13.83	0.80	65.17	13.83	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	79.72	0.37	0.0	67.45	0.37	0.0
FINAL, DEG F	82.97	13.83	0.80	67.99	13.83	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	7.86	0.37	0.0	7.86	0.37	0.0
FINAL BOD, MG/L	0.45	13.83	0.80	0.91	13.83	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.03	0.37	0.0	0.03	0.37	0.0
FINAL BOD IN RIVER	1.33	13.83	0.80	1.70	13.83	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	2.94	0.37	0.0	2.94	0.37	0.0
FINAL BOD, MG/L	0.02	13.83	0.80	0.20	13.83	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	11.81	0.37	0.0	12.29	0.37	0.0
FINAL VALUE, MG/L	1.81	13.83	0.80	2.82	13.83	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	2.15	0.37	0.0	2.15	0.37	0.0
FINAL VALUE, MG/L	0.40	13.83	0.80	0.40	13.83	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	5.18	0.37	0.0	5.18	0.37	0.0
FINAL VALUE, MG/L	3.00	13.83	0.80	3.00	13.83	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.88	0.37	0.0	4.88	0.37	0.0
FINAL VALUE, MG/L	0.84	13.83	0.80	1.84	13.83	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	18.29	0.37	0.0	18.29	0.37	0.0
FINAL PERCENT	0.10	13.83	0.80	0.15	13.83	0.80


1990 LEVEL.SEPT.T.F.
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
MILES DOWNSTREAM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00


1990 LEVEL. SEPT. T.F.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

C. Computer Results for 1990 Design Level,

Trickling Filter and Ames Reservoir, October-November, 10 Yr

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
7.19	60.00	75.00	0.0	24.00	0.080	0.0	12.50	12.50	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
73.00	58.00	130.00	65.00	3.00	0.140	0.0	0.40	3.00	0.40	0.10	70.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.15	115.00	50.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
73.00	58.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	1.50	2.50	1.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 70.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 3.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 11.13 CFS, RIVER Q = 50.00 CFS, TOTAL Q = 61.13 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 1.00 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	73.0	58.0		50.0	10.76	6.41		0.40
0.0	0.37	70.6	58.4	64.5	61.1	10.12	6.55	8.33	2.60
0.01	0.54	70.8	58.3	64.6	61.2	9.85	6.19	8.02	2.52
0.02	0.70	70.9	58.3	64.6	61.2	9.62	5.84	7.73	2.44
0.03	0.87	71.0	58.3	64.7	61.2	9.43	5.53	7.48	2.37
0.04	1.04	71.1	58.3	64.7	61.2	9.27	5.25	7.26	2.29
0.05	1.20	71.2	58.3	64.7	61.3	9.15	5.00	7.07	2.22
0.06	1.37	71.3	58.3	64.8	61.3	9.05	4.78	6.91	2.15
0.07	1.53	71.4	58.2	64.8	61.3	8.98	4.58	6.78	2.09
0.08	1.70	71.5	58.2	64.9	61.3	8.94	4.40	6.67	2.02
0.09	1.87	71.6	58.2	64.9	61.4	8.92	4.23	6.58	1.96
0.10	2.03	71.7	58.2	64.9	61.4	8.92	4.09	6.51	1.90
0.11	2.20	71.7	58.2	65.0	61.4	8.95	3.96	6.45	1.84
0.12	2.37	71.8	58.2	65.0	61.4	8.99	3.84	6.41	1.78
0.13	2.53	71.9	58.2	65.0	61.5	9.05	3.73	6.39	1.73
0.14	2.70	71.9	58.2	65.1	61.5	9.13	3.64	6.38	1.67
0.15	2.87	72.0	58.2	65.1	61.5	9.22	3.55	6.39	1.62
0.16	3.03	72.1	58.1	65.1	61.5	9.33	3.47	6.40	1.57
0.17	3.20	72.1	58.1	65.1	61.6	9.45	3.40	6.43	1.52
0.18	3.37	72.2	58.1	65.1	61.6	9.58	3.34	6.46	1.48
0.19	3.53	72.2	58.1	65.2	61.6	9.72	3.28	6.50	1.43
0.20	3.70	72.3	58.1	65.2	61.6	9.88	3.23	6.55	1.39
0.21	3.87	72.3	58.1	65.2	61.7	10.04	3.19	6.61	1.34
0.22	4.03	72.3	58.1	65.2	61.7	10.21	3.15	6.68	1.30
0.23	4.20	72.4	58.1	65.2	61.7	10.39	3.11	6.75	1.26
0.24	4.37	72.4	58.1	65.2	61.7	10.57	3.08	6.82	1.22
0.25	4.54	72.4	58.1	65.3	61.8	10.76	3.05	6.91	1.19

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	4.70	72.5	58.1	65.3	61.8	10.95	3.03	6.99	1.15
0.27	4.87	72.5	58.1	65.3	61.8	11.14	3.01	7.08	1.12
0.28	5.04	72.5	58.1	65.3	61.8	11.34	2.99	7.17	1.08
0.29	5.20	72.6	58.1	65.3	61.9	11.54	2.98	7.26	1.05
0.30	5.37	72.6	58.1	65.3	61.9	11.74	2.96	7.35	1.02
0.31	5.54	72.6	58.1	65.3	61.9	11.94	2.95	7.45	0.99
0.32	5.70	72.6	58.1	65.3	61.9	12.13	2.95	7.54	0.96
0.33	5.87	72.6	58.1	65.3	62.0	12.33	2.94	7.63	0.93
0.34	6.04	72.7	58.1	65.4	62.0	12.52	2.94	7.73	0.90
0.35	6.21	72.7	58.0	65.4	62.0	12.70	2.94	7.82	0.88
0.36	6.37	72.7	58.0	65.4	62.0	12.88	2.93	7.91	0.85
0.37	6.54	72.7	58.0	65.4	62.1	13.06	2.94	8.00	0.83
0.38	6.71	72.7	58.0	65.4	62.1	13.23	2.94	8.08	0.80
0.39	6.87	72.7	58.0	65.4	62.1	13.39	2.94	8.17	0.78
0.40	7.04	72.8	58.0	65.4	62.1	13.54	2.95	8.25	0.76
0.41	7.21	72.8	58.0	65.4	62.2	13.69	2.95	8.32	0.73
0.42	7.38	72.8	58.0	65.4	62.2	13.83	2.96	8.39	0.71
0.43	7.54	72.8	58.0	65.4	62.2	13.95	2.97	8.46	0.69
0.44	7.71	72.8	58.0	65.4	62.2	14.07	2.97	8.52	0.67
0.45	7.88	72.8	58.0	65.4	62.3	14.18	2.98	8.58	0.66
0.46	8.05	72.8	58.0	65.4	62.3	14.27	2.99	8.63	0.65
0.47	8.21	72.8	58.0	65.4	62.3	14.36	3.00	8.68	0.64
0.48	8.38	72.9	58.0	65.4	62.3	14.43	3.02	8.72	0.63
0.49	8.55	72.9	58.0	65.4	62.4	14.49	3.03	8.76	0.62
0.50	8.72	72.9	58.0	65.4	62.4	14.54	3.04	8.79	0.61
0.51	8.88	72.9	58.0	65.4	62.4	14.57	3.05	8.81	0.60

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	9.05	72.9	58.0	65.4	62.4	14.60	3.07	8.83	0.59
0.53	9.22	72.9	58.0	65.5	62.5	14.61	3.08	8.84	0.58
0.54	9.39	72.9	58.0	65.5	62.5	14.61	3.09	8.85	0.57
0.55	9.55	72.9	58.0	65.5	62.5	14.60	3.11	8.85	0.56
0.56	9.72	72.9	58.0	65.5	62.5	14.57	3.13	8.85	0.56
0.57	9.89	72.9	58.0	65.5	62.6	14.54	3.14	8.84	0.55
0.58	10.06	72.9	58.0	65.5	62.6	14.49	3.16	8.82	0.54
0.59	10.23	72.9	58.0	65.5	62.6	14.43	3.17	8.80	0.53
0.60	10.39	72.9	58.0	65.5	62.6	14.37	3.19	8.78	0.52
0.61	10.56	72.9	58.0	65.5	62.7	14.29	3.21	8.75	0.52
0.62	10.73	72.9	58.0	65.5	62.7	14.20	3.23	8.71	0.51
0.63	10.90	72.9	58.0	65.5	62.7	14.10	3.25	8.68	0.50
0.64	11.06	72.9	58.0	65.5	62.7	14.00	3.27	8.63	0.50
0.65	11.23	72.9	58.0	65.5	62.8	13.88	3.29	8.59	0.49
0.66	11.40	72.9	58.0	65.5	62.8	13.76	3.31	8.54	0.48
0.67	11.57	72.9	58.0	65.5	62.8	13.63	3.33	8.48	0.48
0.68	11.74	73.0	58.0	65.5	62.8	13.50	3.36	8.43	0.47
0.69	11.90	73.0	58.0	65.5	62.9	13.36	3.38	8.37	0.46
0.70	12.07	73.0	58.0	65.5	62.9	13.22	3.41	8.31	0.46
0.71	12.24	73.0	58.0	65.5	62.9	13.07	3.43	8.25	0.45
0.72	12.41	73.0	58.0	65.5	62.9	12.93	3.46	8.19	0.45
0.73	12.58	73.0	58.0	65.5	63.0	12.78	3.49	8.13	0.44
0.74	12.75	73.0	58.0	65.5	63.0	12.62	3.52	8.07	0.44
0.75	12.91	73.0	58.0	65.5	63.0	12.47	3.55	8.01	0.43
0.76	13.08	73.0	58.0	65.5	63.0	12.32	3.58	7.95	0.43
0.77	13.25	73.0	58.0	65.5	63.1	12.17	3.61	7.89	0.42

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	13.42	73.0	58.0	65.5	63.1	12.02	3.65	7.83	0.42
0.79	13.59	73.0	58.0	65.5	63.1	11.88	3.68	7.78	0.41
0.80	13.75	73.0	58.0	65.5	63.1	11.74	3.72	7.73	0.41
0.81	13.92	73.0	58.0	65.5	63.2	11.60	3.75	7.68	0.40
0.82	14.09	73.0	58.0	65.5	63.2	11.47	3.79	7.63	0.40
0.83	14.26	73.0	58.0	65.5	63.2	11.35	3.82	7.58	0.40
0.84	14.43	73.0	58.0	65.5	63.2	11.23	3.86	7.54	0.40
0.85	14.60	73.0	58.0	65.5	63.3	11.12	3.90	7.51	0.40
0.86	14.77	73.0	58.0	65.5	63.3	11.01	3.93	7.47	0.40
0.87	14.93	73.0	58.0	65.5	63.3	10.92	3.96	7.44	0.40
0.88	15.10	73.0	58.0	65.5	63.3	10.83	3.99	7.41	0.40
0.89	15.27	73.0	58.0	65.5	63.4	10.76	4.02	7.39	0.40
0.90	15.44	73.0	58.0	65.5	63.4	10.69	4.05	7.37	0.40
0.91	15.61	73.0	58.0	65.5	63.4	10.63	4.07	7.35	0.40
0.92	15.78	73.0	58.0	65.5	63.4	10.58	4.10	7.34	0.40
0.93	15.94	73.0	58.0	65.5	63.5	10.53	4.12	7.33	0.40
0.94	16.11	73.0	58.0	65.5	63.5	10.49	4.14	7.32	0.40
0.95	16.28	73.0	58.0	65.5	63.5	10.46	4.16	7.31	0.40
0.96	16.45	73.0	58.0	65.5	63.5	10.43	4.17	7.30	0.40
0.97	16.62	73.0	58.0	65.5	63.6	10.40	4.19	7.29	0.40
0.98	16.79	73.0	58.0	65.5	63.6	10.37	4.20	7.29	0.40
0.99	16.96	73.0	58.0	65.5	63.6	10.35	4.22	7.29	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	3.00	1.16	4.16	0.55	4.70	3.00	0.40	0.10
0.0	0.37	8.27	1.39	9.66	3.56	13.22	4.73	4.88	18.29
0.01	0.54	8.05	1.39	9.45	3.45	12.90	4.62	4.83	17.31
0.02	0.70	7.81	1.39	9.20	3.34	12.55	4.52	4.78	16.39
0.03	0.87	7.58	1.38	8.97	3.24	12.21	4.42	4.72	15.51
0.04	1.04	7.36	1.38	8.74	3.14	11.88	4.32	4.67	14.68
0.05	1.20	7.14	1.38	8.52	3.04	11.56	4.22	4.62	13.90
0.06	1.37	6.94	1.38	8.31	2.95	11.26	4.12	4.57	13.16
0.07	1.53	6.73	1.37	8.11	2.85	10.96	4.03	4.53	12.45
0.08	1.70	6.54	1.37	7.91	2.77	10.68	3.93	4.48	11.79
0.09	1.87	6.35	1.37	7.72	2.68	10.40	3.84	4.43	11.16
0.10	2.03	6.17	1.37	7.54	2.60	10.14	3.75	4.38	10.57
0.11	2.20	6.00	1.37	7.37	2.52	9.88	3.67	4.33	10.00
0.12	2.37	5.83	1.37	7.20	2.44	9.63	3.58	4.29	9.47
0.13	2.53	5.66	1.37	7.04	2.36	9.40	3.50	4.24	8.97
0.14	2.70	5.51	1.37	6.88	2.29	9.17	3.42	4.19	8.49
0.15	2.87	5.35	1.37	6.73	2.22	8.94	3.34	4.15	8.04
0.16	3.03	5.21	1.38	6.58	2.15	8.73	3.30	4.10	7.62
0.17	3.20	5.06	1.38	6.44	2.08	8.52	3.27	4.06	7.21
0.18	3.37	4.92	1.38	6.31	2.02	8.32	3.24	4.02	6.83
0.19	3.53	4.79	1.38	6.18	1.96	8.13	3.21	3.97	6.47
0.20	3.70	4.66	1.39	6.05	1.90	7.95	3.18	3.93	6.13
0.21	3.87	4.54	1.39	5.93	1.84	7.77	3.15	3.89	5.81
0.22	4.03	4.42	1.39	5.81	1.78	7.59	3.12	3.84	5.50
0.23	4.20	4.30	1.40	5.70	1.73	7.43	3.10	3.80	5.22
0.24	4.37	4.18	1.40	5.59	1.68	7.26	3.07	3.76	4.94
0.25	4.54	4.08	1.41	5.48	1.62	7.11	3.04	3.72	4.68

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	4.70	3.97	1.41	5.38	1.58	6.96	3.01	3.68	4.44
0.27	4.87	3.87	1.42	5.28	1.53	6.81	3.00	3.64	4.21
0.28	5.04	3.77	1.42	5.19	1.48	6.67	3.00	3.60	3.99
0.29	5.20	3.67	1.43	5.10	1.44	6.54	3.00	3.56	3.78
0.30	5.37	3.57	1.44	5.01	1.39	6.41	3.00	3.52	3.59
0.31	5.54	3.48	1.44	4.93	1.35	6.28	3.00	3.49	3.40
0.32	5.70	3.39	1.45	4.84	1.31	6.16	3.00	3.45	3.23
0.33	5.87	3.31	1.46	4.77	1.27	6.04	3.00	3.41	3.06
0.34	6.04	3.23	1.46	4.69	1.24	5.92	3.00	3.37	2.90
0.35	6.21	3.15	1.47	4.62	1.20	5.81	3.00	3.34	2.75
0.36	6.37	3.07	1.48	4.54	1.16	5.71	3.00	3.30	2.61
0.37	6.54	2.99	1.49	4.48	1.13	5.61	3.00	3.27	2.48
0.38	6.71	2.92	1.49	4.41	1.10	5.51	3.00	3.23	2.35
0.39	6.87	2.85	1.50	4.35	1.06	5.41	3.00	3.20	2.23
0.40	7.04	2.78	1.51	4.28	1.03	5.32	3.00	3.16	2.12
0.41	7.21	2.71	1.52	4.23	1.00	5.23	3.00	3.13	2.01
0.42	7.38	2.64	1.53	4.17	0.97	5.14	3.00	3.09	1.91
0.43	7.54	2.58	1.53	4.11	0.95	5.06	3.00	3.06	1.81
0.44	7.71	2.52	1.54	4.06	0.92	4.98	3.00	3.03	1.72
0.45	7.89	2.46	1.55	4.01	0.89	4.90	3.00	3.00	1.64
0.46	8.05	2.40	1.56	3.96	0.87	4.83	3.00	2.96	1.55
0.47	8.21	2.34	1.57	3.91	0.84	4.75	3.00	2.93	1.48
0.48	8.38	2.28	1.58	3.87	0.82	4.68	3.00	2.90	1.40
0.49	8.55	2.23	1.59	3.82	0.80	4.62	3.00	2.87	1.33
0.50	8.72	2.18	1.60	3.78	0.77	4.55	3.00	2.84	1.27
0.51	8.88	2.13	1.61	3.74	0.75	4.49	3.00	2.81	1.20

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	9.05	2.08	1.62	3.70	0.73	4.43	3.00	2.78	1.14
0.53	9.22	2.03	1.63	3.66	0.71	4.37	3.00	2.75	1.09
0.54	9.39	1.98	1.64	3.62	0.69	4.31	3.00	2.72	1.03
0.55	9.55	1.94	1.65	3.59	0.67	4.26	3.00	2.69	0.98
0.56	9.72	1.89	1.66	3.55	0.65	4.20	3.00	2.66	0.93
0.57	9.89	1.85	1.67	3.52	0.63	4.15	3.00	2.63	0.89
0.58	10.06	1.81	1.68	3.49	0.62	4.10	3.00	2.61	0.84
0.59	10.23	1.76	1.69	3.46	0.60	4.06	3.00	2.58	0.80
0.60	10.39	1.72	1.70	3.43	0.58	4.01	3.00	2.55	0.76
0.61	10.56	1.69	1.71	3.40	0.57	3.97	3.00	2.52	0.73
0.62	10.73	1.65	1.72	3.37	0.55	3.92	3.00	2.50	0.69
0.63	10.90	1.61	1.73	3.34	0.54	3.88	3.00	2.47	0.66
0.64	11.06	1.57	1.75	3.32	0.52	3.84	3.00	2.45	0.63
0.65	11.23	1.54	1.76	3.29	0.51	3.80	3.00	2.42	0.59
0.66	11.40	1.50	1.77	3.27	0.49	3.77	3.00	2.39	0.57
0.67	11.57	1.47	1.78	3.25	0.48	3.73	3.00	2.37	0.54
0.68	11.74	1.44	1.79	3.23	0.47	3.70	3.00	2.34	0.51
0.69	11.90	1.41	1.80	3.21	0.46	3.66	3.00	2.32	0.49
0.70	12.07	1.37	1.81	3.19	0.44	3.63	3.00	2.30	0.46
0.71	12.24	1.34	1.82	3.17	0.43	3.60	3.00	2.27	0.44
0.72	12.41	1.31	1.84	3.15	0.42	3.57	3.00	2.25	0.42
0.73	12.58	1.29	1.85	3.13	0.41	3.54	3.00	2.22	0.40
0.74	12.75	1.26	1.86	3.12	0.40	3.52	3.00	2.20	0.38
0.75	12.91	1.23	1.87	3.10	0.39	3.49	3.00	2.18	0.36
0.76	13.08	1.20	1.88	3.08	0.38	3.46	3.00	2.16	0.35
0.77	13.25	1.18	1.89	3.07	0.37	3.44	3.00	2.13	0.33

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

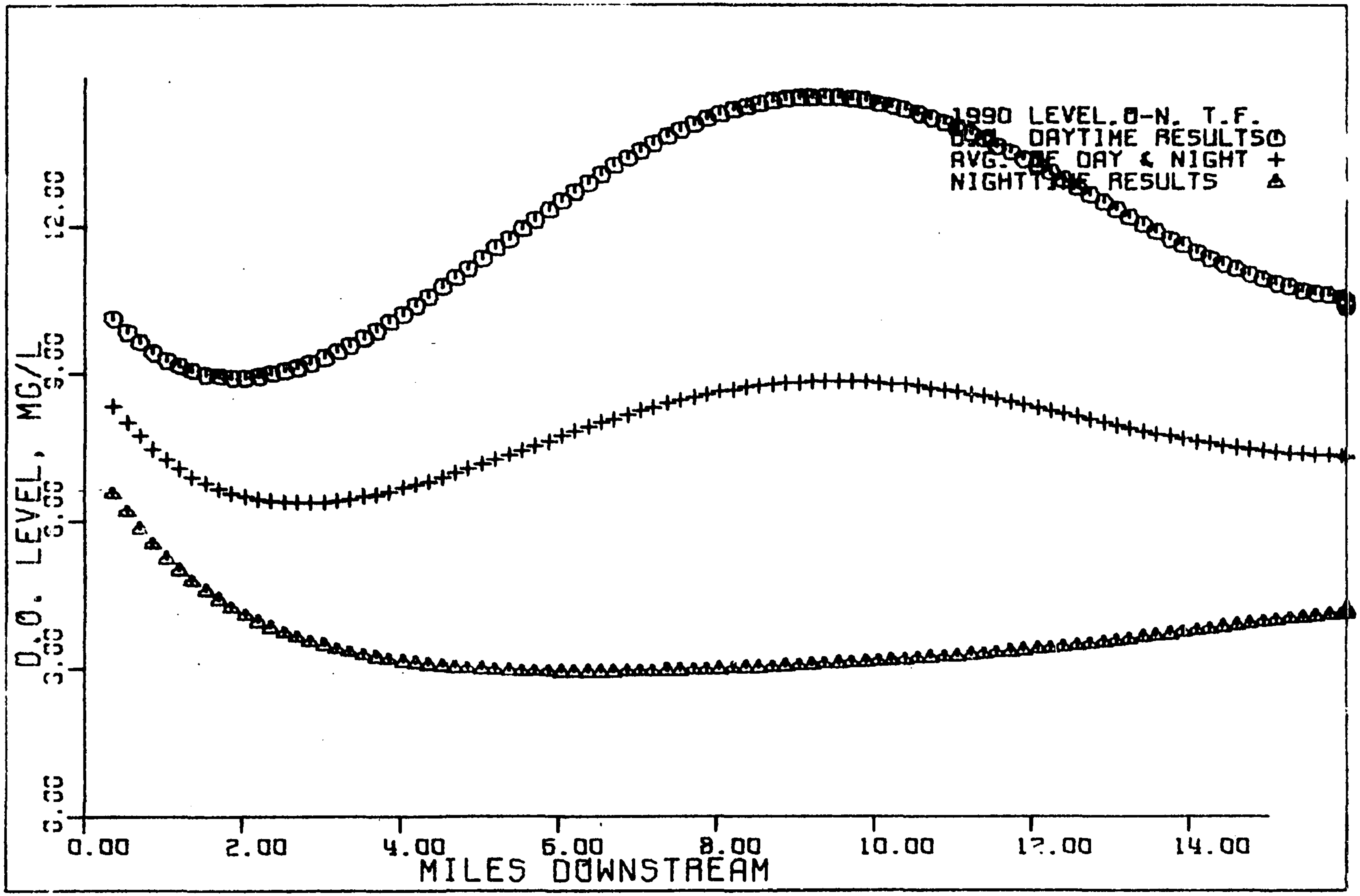
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	13.42	1.15	1.91	3.06	0.36	3.42	3.00	2.11	0.32
0.79	13.59	1.13	1.92	3.04	0.35	3.39	3.00	2.09	0.30
0.80	13.75	1.10	1.93	3.03	0.34	3.37	3.00	2.07	0.29
0.81	13.92	1.08	1.94	3.02	0.33	3.35	3.00	2.05	0.28
0.82	14.09	1.05	1.95	3.01	0.32	3.33	3.00	2.03	0.27
0.83	14.26	1.03	1.97	3.00	0.32	3.31	3.00	2.00	0.26
0.84	14.43	1.01	1.98	2.99	0.31	3.29	3.00	1.98	0.25
0.85	14.60	0.99	1.99	2.98	0.30	3.28	3.00	1.96	0.24
0.86	14.77	0.97	2.00	2.97	0.29	3.26	3.00	1.94	0.24
0.87	14.93	0.94	2.01	2.96	0.28	3.24	3.00	1.92	0.23
0.88	15.10	0.92	2.02	2.95	0.28	3.23	3.00	1.90	0.22
0.89	15.27	0.90	2.04	2.94	0.27	3.21	3.00	1.88	0.21
0.90	15.44	0.89	2.05	2.93	0.26	3.20	3.00	1.87	0.21
0.91	15.61	0.87	2.06	2.93	0.26	3.18	3.00	1.85	0.20
0.92	15.78	0.85	2.07	2.92	0.25	3.17	3.00	1.83	0.19
0.93	15.94	0.83	2.08	2.91	0.24	3.16	3.00	1.81	0.19
0.94	16.11	0.81	2.10	2.91	0.24	3.15	3.00	1.79	0.18
0.95	16.28	0.80	2.11	2.90	0.23	3.14	3.00	1.77	0.17
0.96	16.45	0.78	2.12	2.90	0.23	3.13	3.00	1.75	0.17
0.97	16.62	0.76	2.13	2.89	0.22	3.12	3.00	1.74	0.16
0.98	16.79	0.75	2.15	2.89	0.22	3.11	3.00	1.72	0.16
0.99	16.96	0.73	2.16	2.89	0.21	3.10	3.00	1.70	0.15

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

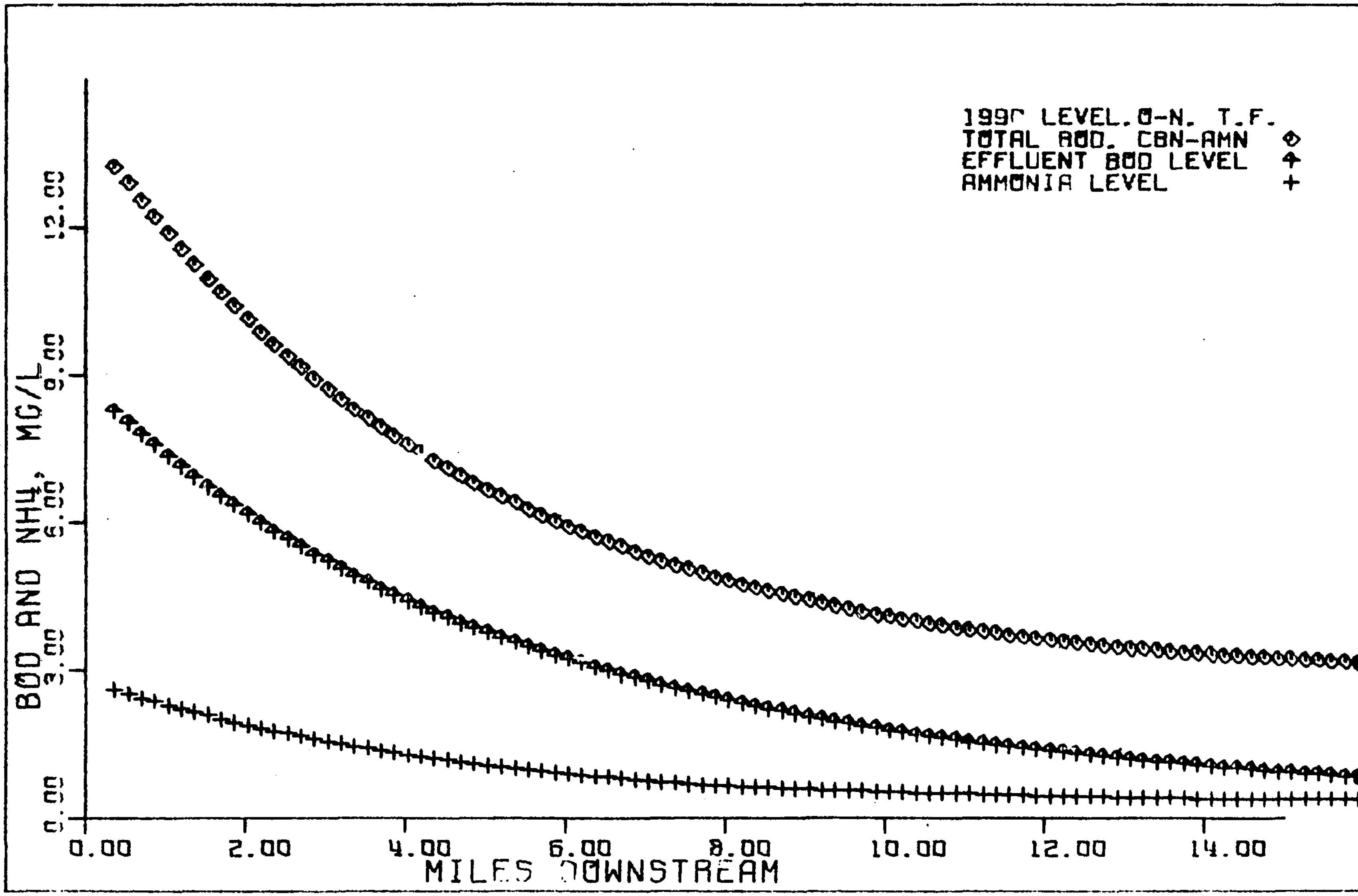
STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	10.12	0.37	0.0	6.55	0.37	0.0
MINIMUM DO, MG/L	8.92	1.87	0.09	2.93	6.37	0.36
FINAL DO, MG/L	11.74	13.75	0.80	3.72	13.75	0.80
DO DEFICIT						
INITIAL, MG/L	-1.62	0.37	0.0	3.26	0.37	0.0
FINAL, MG/L	-3.46	13.75	0.80	6.14	13.75	0.80
RIVER DISCHARGE						
INITIAL, CFS	61.13	0.37	0.0	61.13	0.37	0.0
FINAL, CFS	63.14	13.75	0.80	63.14	13.75	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	70.63	0.37	0.0	58.36	0.37	0.0
FINAL, DEG F	72.98	13.75	0.80	58.00	13.75	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	8.27	0.37	0.0	8.27	0.37	0.0
FINAL BOD, MG/L	0.78	13.75	0.80	1.42	13.75	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.70	13.75	0.80	2.16	13.75	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	3.56	0.37	0.0	3.56	0.37	0.0
FINAL BOD, MG/L	0.12	13.75	0.80	0.56	13.75	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	12.98	0.37	0.0	13.45	0.37	0.0
FINAL VALUE, MG/L	2.60	13.75	0.80	4.14	13.75	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	2.60	0.37	0.0	2.60	0.37	0.0
FINAL VALUE, MG/L	0.40	13.75	0.80	0.41	13.75	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.73	0.37	0.0	4.73	0.37	0.0
FINAL VALUE, MG/L	3.00	13.75	0.80	3.00	13.75	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.88	0.37	0.0	4.88	0.37	0.0
FINAL VALUE, MG/L	1.55	13.75	0.80	2.59	13.75	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	18.29	0.37	0.0	18.29	0.37	0.0
FINAL PERCENT	0.10	13.75	0.80	0.49	13.75	0.80



DAYTIME RESULTS
AVG. DAY & NIGHT +
RESULTS
D.O. LEVEL, MG/L
0.00
2.00
4.00
6.00
8.00
10.00
14.00
MILES DOWNSTREAM



199Γ LEVEL.O-N. T.F.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

D. Computer Results for 1990 Design Level, Trickling Filter and Ames Reservoir, Winter, 10 Yr, Low Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
5.88	50.00	75.00	0.0	44.00	0.080	0.0	20.00	10.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDOCY	DLOCY	ILGCY	OPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
     SEASON : WINTER

 GAMMA1 =    0.80  , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    9.10 CFS, RIVER Q =  50.00 CFS, TOTAL Q =  59.10 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		50.0	12.79	9.95		0.40
0.0	0.37	34.8	34.8	34.8	59.1	12.08	9.68	10.88	3.42
0.02	0.70	34.5	34.5	34.5	59.1	11.87	9.82	10.85	3.36
0.04	1.03	34.2	34.2	34.2	59.2	11.70	9.93	10.81	3.30
0.06	1.36	34.0	34.0	34.0	59.2	11.57	10.04	10.80	3.25
0.08	1.68	33.7	33.7	33.7	59.2	11.47	10.14	10.80	3.19
0.10	2.01	33.6	33.6	33.6	59.3	11.39	10.24	10.82	3.14
0.12	2.34	33.4	33.4	33.4	59.3	11.34	10.34	10.84	3.09
0.14	2.67	33.2	33.2	33.2	59.3	11.30	10.44	10.87	3.04
0.16	3.00	33.1	33.1	33.1	59.4	11.28	10.53	10.91	2.99
0.18	3.33	33.0	33.0	33.0	59.4	11.27	10.62	10.95	2.94
0.20	3.66	32.9	32.9	32.9	59.4	11.27	10.71	10.99	2.90
0.22	3.99	32.8	32.8	32.8	59.5	11.28	10.79	11.04	2.85
0.24	4.32	32.7	32.7	32.7	59.5	11.30	10.87	11.08	2.81
0.26	4.65	32.6	32.6	32.6	59.5	11.32	10.95	11.13	2.76
0.28	4.97	32.6	32.6	32.6	59.6	11.35	11.02	11.19	2.72
0.30	5.30	32.5	32.5	32.5	59.6	11.38	11.10	11.24	2.68
0.32	5.63	32.4	32.4	32.4	59.6	11.07	10.79	10.93	2.63
0.34	5.96	32.4	32.4	32.4	59.7	10.78	10.50	10.64	2.59
0.36	6.29	32.3	32.3	32.3	59.7	10.49	10.21	10.35	2.55
0.38	6.62	32.3	32.3	32.3	59.7	10.21	9.93	10.07	2.51
0.40	6.95	32.3	32.3	32.3	59.8	9.94	9.66	9.80	2.47
0.42	7.28	32.2	32.2	32.2	59.8	9.67	9.40	9.54	2.44
0.44	7.61	32.2	32.2	32.2	59.8	9.42	9.15	9.28	2.40
0.46	7.94	32.2	32.2	32.2	59.9	9.17	8.90	9.04	2.36
0.48	8.27	32.2	32.2	32.2	59.9	8.93	8.66	8.80	2.33
0.50	8.60	32.2	32.2	32.2	59.9	8.70	8.43	8.56	2.29

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.93	32.1	32.1	32.1	60.0	8.47	8.21	8.34	2.25
0.54	9.26	32.1	32.1	32.1	60.0	8.25	7.99	8.12	2.22
0.56	9.59	32.1	32.1	32.1	60.0	8.04	7.78	7.91	2.19
0.58	9.92	32.1	32.1	32.1	60.1	7.83	7.57	7.70	2.15
0.60	10.25	32.1	32.1	32.1	60.1	7.63	7.38	7.50	2.12
0.62	10.58	32.1	32.1	32.1	60.1	7.44	7.18	7.31	2.09
0.64	10.91	32.1	32.1	32.1	60.2	7.25	7.00	7.12	2.06
0.66	11.24	32.1	32.1	32.1	60.2	7.07	6.82	6.94	2.02
0.68	11.58	32.1	32.1	32.1	60.2	6.89	6.64	6.77	1.99
0.70	11.91	32.0	32.0	32.0	60.3	6.72	6.48	6.60	1.96
0.72	12.24	32.0	32.0	32.0	60.3	6.56	6.31	6.44	1.93
0.74	12.57	32.0	32.0	32.0	60.3	6.40	6.15	6.28	1.90
0.76	12.90	32.0	32.0	32.0	60.4	6.24	6.00	6.12	1.87
0.78	13.23	32.0	32.0	32.0	60.4	6.09	5.85	5.97	1.85
0.80	13.56	32.0	32.0	32.0	60.4	5.95	5.71	5.83	1.82
0.82	13.89	32.0	32.0	32.0	60.5	5.81	5.57	5.69	1.79
0.84	14.22	32.0	32.0	32.0	60.5	5.67	5.44	5.56	1.76
0.86	14.55	32.0	32.0	32.0	60.5	5.54	5.31	5.43	1.74
0.88	14.89	32.0	32.0	32.0	60.6	5.42	5.18	5.30	1.71
0.90	15.22	32.0	32.0	32.0	60.6	5.29	5.06	5.18	1.68
0.92	15.55	32.0	32.0	32.0	60.6	5.17	4.94	5.06	1.66
0.94	15.88	32.0	32.0	32.0	60.7	5.06	4.83	4.94	1.63
0.96	16.21	32.0	32.0	32.0	60.7	4.95	4.72	4.83	1.61
0.98	16.54	32.0	32.0	32.0	60.7	4.84	4.61	4.73	1.58
1.00	16.88	32.0	32.0	32.0	60.8	4.73	4.51	4.62	1.56
1.02	17.21	32.0	32.0	32.0	60.8	4.63	4.41	4.52	1.54

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	17.54	32.0	32.0	32.0	60.8	4.53	4.31	4.42	1.51
1.06	17.87	32.0	32.0	32.0	60.9	4.44	4.22	4.33	1.49
1.08	18.20	32.0	32.0	32.0	60.9	4.35	4.13	4.24	1.47
1.10	18.54	32.0	32.0	32.0	60.9	4.26	4.04	4.15	1.44
1.12	18.87	32.0	32.0	32.0	61.0	4.17	3.96	4.07	1.42
1.14	19.20	32.0	32.0	32.0	61.0	4.09	3.88	3.98	1.40
1.16	19.53	32.0	32.0	32.0	61.0	4.01	3.80	3.90	1.38
1.18	19.87	32.0	32.0	32.0	61.1	3.93	3.72	3.83	1.36
1.20	20.20	32.0	32.0	32.0	61.1	3.85	3.65	3.75	1.34
1.22	20.53	32.0	32.0	32.0	61.1	3.78	3.58	3.68	1.32
1.24	20.86	32.0	32.0	32.0	61.2	3.71	3.51	3.61	1.30
1.26	21.20	32.0	32.0	32.0	61.2	3.64	3.44	3.54	1.28
1.28	21.53	32.0	32.0	32.0	61.2	3.57	3.37	3.47	1.26
1.30	21.86	32.0	32.0	32.0	61.3	3.51	3.31	3.41	1.24
1.32	22.19	32.0	32.0	32.0	61.3	3.45	3.25	3.35	1.22
1.34	22.53	32.0	32.0	32.0	61.3	3.39	3.19	3.29	1.20
1.36	22.86	32.0	32.0	32.0	61.4	3.33	3.13	3.23	1.18
1.38	23.19	32.0	32.0	32.0	61.4	3.27	3.08	3.17	1.17
1.40	23.53	32.0	32.0	32.0	61.4	3.21	3.02	3.12	1.15
1.42	23.86	32.0	32.0	32.0	61.5	3.16	2.97	3.07	1.13
1.44	24.19	32.0	32.0	32.0	61.5	3.11	2.92	3.01	1.11
1.46	24.53	32.0	32.0	32.0	61.5	3.06	2.87	2.96	1.10
1.48	24.86	32.0	32.0	32.0	61.6	3.01	2.82	2.92	1.08
1.50	25.19	32.0	32.0	32.0	61.6	2.96	2.78	2.87	1.06
1.52	25.53	32.0	32.0	32.0	61.6	2.91	2.73	2.82	1.05
1.54	25.86	32.0	32.0	32.0	61.7	2.87	2.69	2.78	1.03

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	RIVER TEMP-ERATURE NIGHT DEG F	RIVER TEMP-ERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	26.19	32.0	32.0	32.0	61.7	2.82	2.65	2.73	1.02
1.58	26.53	32.0	32.0	32.0	61.7	2.78	2.60	2.69	1.00
1.60	26.86	32.0	32.0	32.0	61.8	2.74	2.56	2.65	0.99
1.62	27.19	32.0	32.0	32.0	61.8	2.69	2.52	2.61	0.97
1.64	27.53	32.0	32.0	32.0	61.8	2.65	2.48	2.57	0.96
1.66	27.86	32.0	32.0	32.0	61.9	2.61	2.45	2.53	0.94
1.68	28.20	32.0	32.0	32.0	61.9	2.58	2.41	2.49	0.93
1.70	28.53	32.0	32.0	32.0	61.9	2.54	2.37	2.46	0.91
1.72	28.87	32.0	32.0	32.0	62.0	2.50	2.34	2.42	0.90
1.74	29.20	32.0	32.0	32.0	62.0	2.46	2.30	2.38	0.89
1.76	29.53	32.0	32.0	32.0	62.0	2.43	2.27	2.35	0.87
1.78	29.87	32.0	32.0	32.0	62.1	2.39	2.23	2.31	0.86
1.80	30.20	32.0	32.0	32.0	62.1	2.36	2.20	2.28	0.85
1.82	30.54	32.0	32.0	32.0	62.1	2.32	2.17	2.24	0.83
1.84	30.87	32.0	32.0	32.0	62.2	2.29	2.13	2.21	0.82
1.86	31.21	32.0	32.0	32.0	62.2	2.26	2.10	2.18	0.81
1.88	31.54	32.0	32.0	32.0	62.2	2.22	2.07	2.15	0.80
1.90	31.88	32.0	32.0	32.0	62.3	2.19	2.04	2.11	0.78
1.92	32.21	32.0	32.0	32.0	62.3	2.16	2.00	2.08	0.77
1.94	32.55	32.0	32.0	32.0	62.3	2.12	1.97	2.05	0.76
1.96	32.88	32.0	32.0	32.0	62.4	2.09	1.94	2.02	0.75
1.98	33.22	32.0	32.0	32.0	62.4	2.06	1.91	1.98	0.74

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER					NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
		EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L			
0.0	0.0	2.00	0.66	2.66	0.55	3.21	3.00	0.40	0.10
0.0	0.37	10.70	0.75	11.45	4.68	16.13	4.08	4.96	15.49
0.02	0.70	10.43	0.77	11.20	4.60	15.80	4.04	4.93	14.75
0.04	1.03	10.13	0.79	10.92	4.52	15.44	4.00	4.90	14.06
0.06	1.36	9.85	0.81	10.65	4.44	15.10	3.96	4.87	13.41
0.08	1.68	9.57	0.83	10.40	4.37	14.77	3.92	4.84	12.79
0.10	2.01	9.30	0.85	10.15	4.30	14.45	3.88	4.81	12.20
0.12	2.34	9.05	0.87	9.91	4.23	14.14	3.85	4.79	11.64
0.14	2.67	8.80	0.89	9.68	4.16	13.84	3.81	4.76	11.11
0.16	3.00	8.56	0.91	9.46	4.09	13.56	3.77	4.73	10.61
0.18	3.33	8.33	0.92	9.25	4.03	13.28	3.74	4.70	10.13
0.20	3.66	8.11	0.94	9.05	3.96	13.01	3.70	4.68	9.67
0.22	3.99	7.89	0.96	8.85	3.90	12.75	3.67	4.65	9.24
0.24	4.32	7.68	0.98	8.67	3.84	12.50	3.63	4.62	8.82
0.26	4.65	7.48	1.00	8.48	3.78	12.26	3.60	4.60	8.43
0.28	4.97	7.29	1.02	8.31	3.72	12.03	3.57	4.57	8.05
0.30	5.30	7.10	1.04	8.14	3.66	11.80	3.53	4.55	7.70
0.32	5.63	6.92	1.06	7.98	3.60	11.58	3.50	4.52	7.35
0.34	5.96	6.74	1.08	7.82	3.55	11.37	3.46	4.50	7.03
0.36	6.29	6.57	1.10	7.67	3.49	11.16	3.43	4.47	6.72
0.38	6.62	6.40	1.12	7.52	3.44	10.96	3.40	4.45	6.42
0.40	6.95	6.24	1.14	7.38	3.39	10.76	3.37	4.42	6.13
0.42	7.28	6.08	1.16	7.24	3.33	10.57	3.33	4.40	5.86
0.44	7.61	5.93	1.17	7.11	3.28	10.39	3.30	4.38	5.60
0.46	7.94	5.79	1.19	6.98	3.23	10.21	3.27	4.35	5.36
0.48	8.27	5.64	1.21	6.85	3.18	10.04	3.24	4.33	5.12
0.50	8.60	5.50	1.23	6.74	3.13	9.87	3.21	4.30	4.90

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.93	5.37	1.25	6.62	3.08	9.70	3.18	4.28	4.68
0.54	9.26	5.24	1.27	6.51	3.04	9.54	3.15	4.26	4.47
0.56	9.59	5.11	1.29	6.40	2.99	9.39	3.12	4.23	4.28
0.58	9.92	4.99	1.31	6.29	2.94	9.24	3.09	4.21	4.09
0.60	10.25	4.87	1.33	6.19	2.90	9.09	3.06	4.19	3.91
0.62	10.58	4.75	1.35	6.09	2.86	8.95	3.03	4.16	3.74
0.64	10.91	4.63	1.36	6.00	2.81	8.81	3.00	4.14	3.57
0.66	11.24	4.52	1.38	5.91	2.77	8.68	3.00	4.12	3.42
0.68	11.58	4.42	1.40	5.82	2.73	8.55	3.00	4.10	3.27
0.70	11.91	4.31	1.42	5.73	2.68	8.42	3.00	4.07	3.12
0.72	12.24	4.21	1.44	5.65	2.64	8.29	3.00	4.05	2.99
0.74	12.57	4.11	1.46	5.57	2.60	8.17	3.00	4.03	2.85
0.76	12.90	4.01	1.48	5.49	2.56	8.06	3.00	4.01	2.73
0.78	13.23	3.92	1.50	5.42	2.52	7.94	3.00	3.99	2.61
0.80	13.56	3.83	1.52	5.34	2.49	7.83	3.00	3.97	2.49
0.82	13.89	3.74	1.53	5.27	2.45	7.72	3.00	3.94	2.39
0.84	14.22	3.65	1.55	5.21	2.41	7.62	3.00	3.92	2.28
0.86	14.55	3.57	1.57	5.14	2.37	7.51	3.00	3.90	2.18
0.88	14.89	3.49	1.59	5.08	2.34	7.41	3.00	3.88	2.08
0.90	15.22	3.41	1.61	5.02	2.30	7.32	3.00	3.86	1.99
0.92	15.55	3.33	1.63	4.96	2.27	7.22	3.00	3.84	1.91
0.94	15.88	3.25	1.65	4.90	2.23	7.13	3.00	3.82	1.82
0.96	16.21	3.18	1.67	4.84	2.20	7.04	3.00	3.80	1.74
0.98	16.54	3.11	1.68	4.79	2.17	6.96	3.00	3.78	1.67
1.00	16.88	3.04	1.70	4.74	2.13	6.87	3.00	3.76	1.59
1.02	17.21	2.97	1.72	4.69	2.10	6.79	3.00	3.74	1.52

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	17.54	2.90	1.74	4.64	2.07	6.71	3.00	3.71	1.46
1.06	17.87	2.83	1.76	4.59	2.04	6.63	3.00	3.69	1.39
1.08	18.20	2.77	1.78	4.55	2.01	6.55	3.00	3.67	1.33
1.10	18.54	2.71	1.80	4.51	1.98	6.48	3.00	3.65	1.27
1.12	18.87	2.65	1.81	4.46	1.95	6.41	3.00	3.63	1.22
1.14	19.20	2.59	1.83	4.42	1.92	6.34	3.00	3.62	1.16
1.16	19.53	2.53	1.85	4.38	1.89	6.27	3.00	3.60	1.11
1.18	19.87	2.48	1.87	4.35	1.86	6.21	3.00	3.58	1.06
1.20	20.20	2.42	1.89	4.31	1.83	6.14	3.00	3.56	1.02
1.22	20.53	2.37	1.91	4.28	1.80	6.08	3.00	3.54	0.97
1.24	20.86	2.32	1.93	4.24	1.77	6.02	3.00	3.52	0.93
1.26	21.20	2.27	1.95	4.21	1.75	5.96	3.00	3.50	0.89
1.28	21.53	2.22	1.96	4.18	1.72	5.90	3.00	3.48	0.85
1.30	21.86	2.17	1.98	4.15	1.70	5.85	3.00	3.46	0.81
1.32	22.19	2.12	2.00	4.12	1.67	5.79	3.00	3.44	0.78
1.34	22.53	2.07	2.02	4.09	1.64	5.74	3.00	3.42	0.74
1.36	22.86	2.03	2.04	4.07	1.62	5.69	3.00	3.41	0.71
1.38	23.19	1.99	2.06	4.04	1.59	5.64	3.00	3.39	0.68
1.40	23.53	1.94	2.08	4.02	1.57	5.59	3.00	3.37	0.65
1.42	23.86	1.90	2.09	4.00	1.55	5.54	3.00	3.35	0.62
1.44	24.19	1.86	2.11	3.97	1.52	5.50	3.00	3.33	0.59
1.46	24.53	1.82	2.13	3.95	1.50	5.45	3.00	3.31	0.57
1.48	24.86	1.78	2.15	3.93	1.48	5.41	3.00	3.30	0.54
1.50	25.19	1.74	2.17	3.91	1.46	5.37	3.00	3.28	0.52
1.52	25.53	1.70	2.19	3.89	1.43	5.33	3.00	3.26	0.50
1.54	25.86	1.67	2.21	3.87	1.41	5.29	3.00	3.24	0.48

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

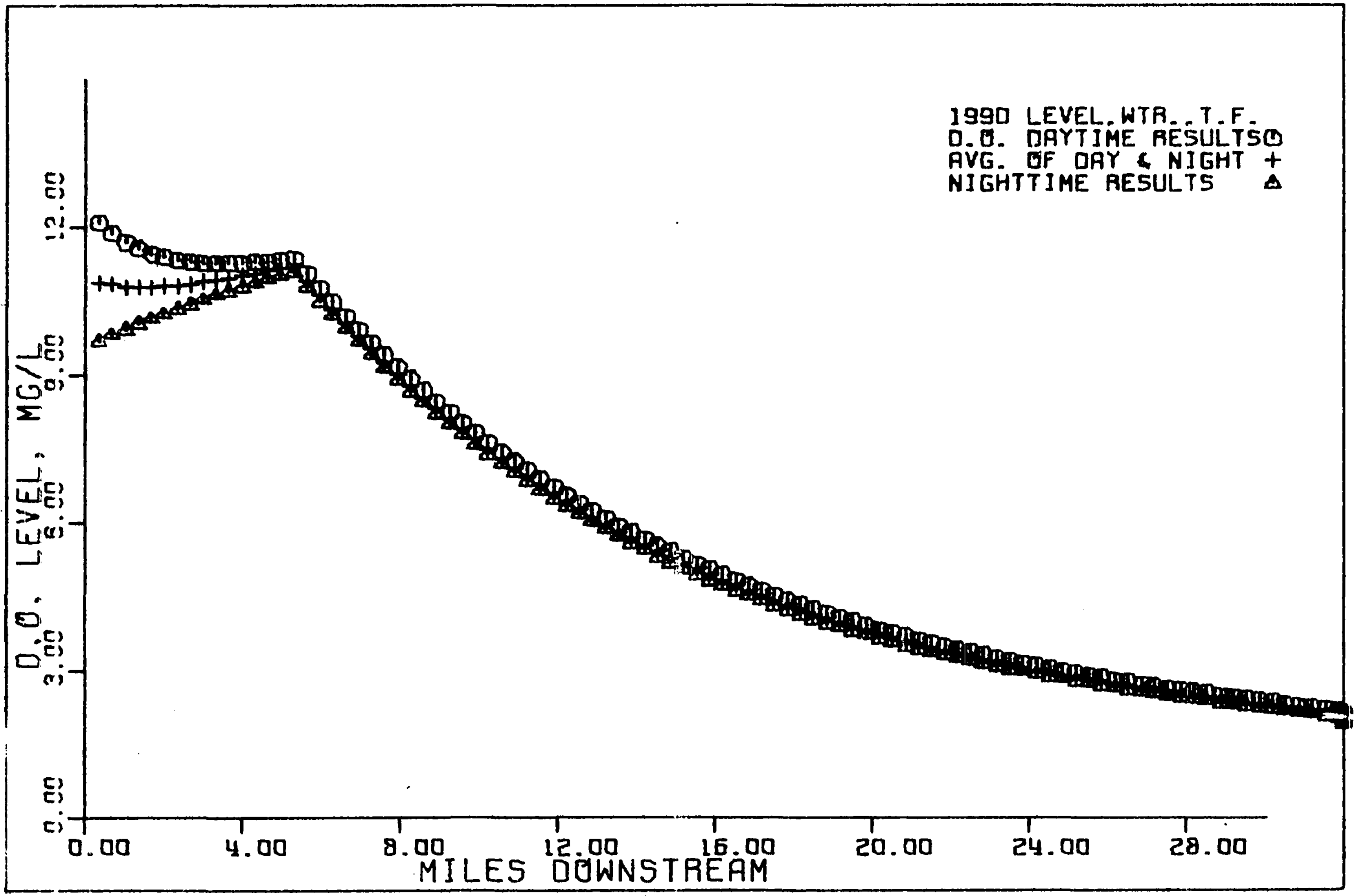
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	26.19	1.63	2.23	3.86	1.39	5.25	3.00	3.23	0.45
1.58	26.53	1.60	2.24	3.84	1.37	5.21	3.00	3.21	0.43
1.60	26.86	1.56	2.26	3.83	1.35	5.17	3.00	3.19	0.42
1.62	27.19	1.53	2.28	3.81	1.33	5.14	3.00	3.17	0.40
1.64	27.53	1.50	2.30	3.80	1.31	5.11	3.00	3.16	0.38
1.66	27.86	1.47	2.32	3.78	1.29	5.07	3.00	3.14	0.36
1.68	28.20	1.44	2.34	3.77	1.27	5.04	3.00	3.12	0.35
1.70	28.53	1.41	2.36	3.76	1.25	5.01	3.00	3.11	0.33
1.72	28.87	1.38	2.37	3.75	1.23	4.98	3.00	3.09	0.32
1.74	29.20	1.35	2.39	3.74	1.21	4.95	3.00	3.07	0.30
1.76	29.53	1.32	2.41	3.73	1.19	4.92	3.00	3.06	0.29
1.78	29.87	1.29	2.43	3.72	1.18	4.90	3.00	3.04	0.28
1.80	30.20	1.26	2.45	3.71	1.16	4.87	3.00	3.02	0.27
1.82	30.54	1.24	2.47	3.70	1.14	4.84	3.00	3.01	0.25
1.84	30.87	1.21	2.48	3.70	1.12	4.82	3.00	2.99	0.24
1.86	31.21	1.19	2.50	3.69	1.11	4.79	3.00	2.97	0.23
1.88	31.54	1.16	2.52	3.68	1.09	4.77	3.00	2.96	0.22
1.90	31.88	1.14	2.54	3.68	1.07	4.75	3.00	2.94	0.21
1.92	32.21	1.11	2.56	3.67	1.06	4.73	3.00	2.93	0.20
1.94	32.55	1.09	2.58	3.67	1.04	4.71	3.00	2.91	0.19
1.96	32.88	1.07	2.59	3.66	1.03	4.69	3.00	2.89	0.19
1.98	33.22	1.05	2.61	3.66	1.01	4.67	3.00	2.88	0.18

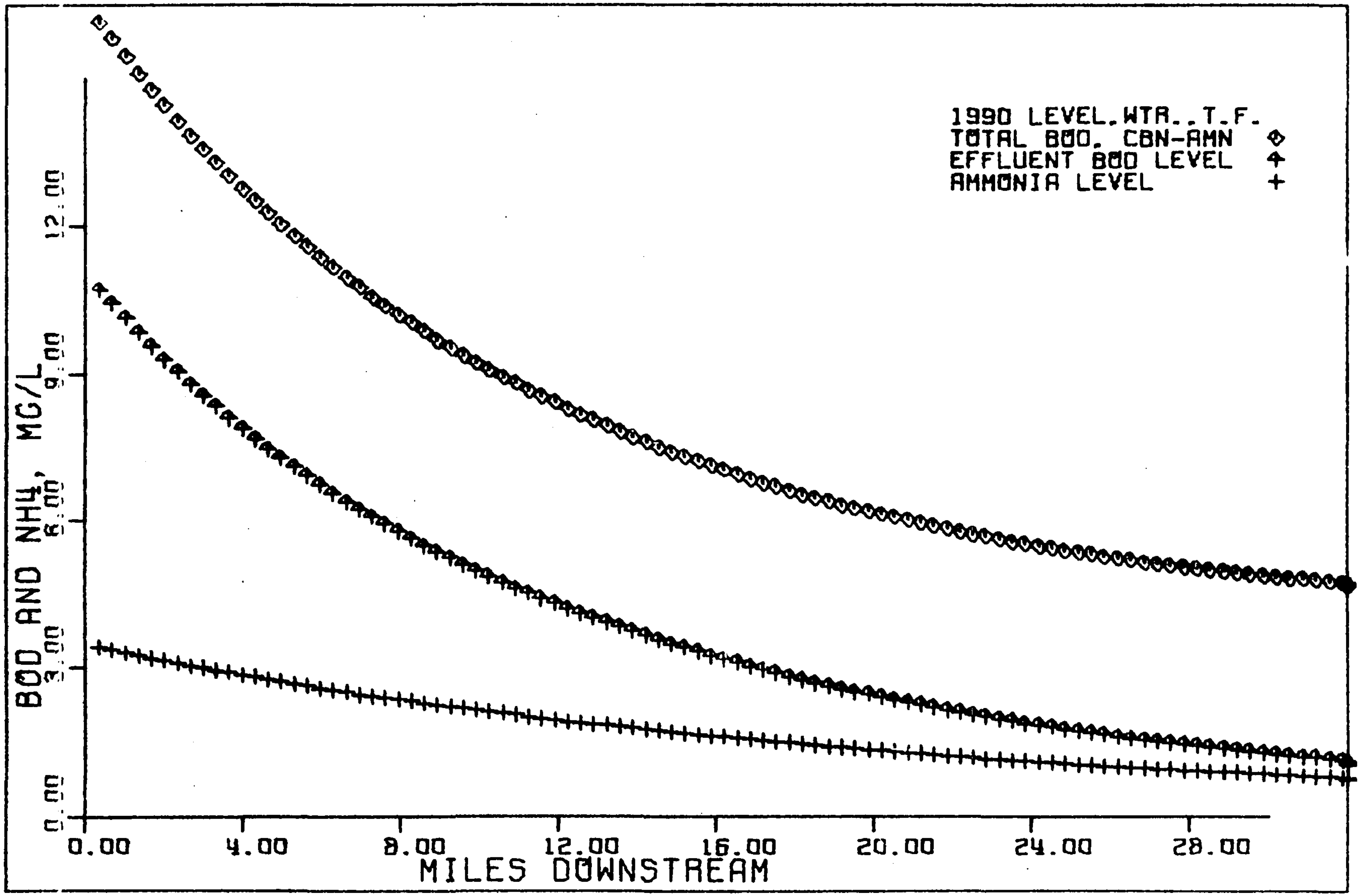
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	12.08	0.37	0.0	9.68	0.37	0.0
MINIMUM DO, MG/L	2.06	33.22	1.98	1.91	33.22	1.98
FINAL DO, MG/L	5.95	13.56	0.80	5.71	13.56	0.80
DO DEFICIT						
INITIAL, MG/L	1.53	0.37	0.0	3.94	0.37	0.0
FINAL, MG/L	8.26	13.56	0.80	8.50	13.56	0.80
RIVER DISCHARGE						
INITIAL, CFS	59.10	0.37	0.0	59.10	0.37	0.0
FINAL, CFS	60.42	13.56	0.80	60.42	13.56	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	34.77	0.37	0.0	34.77	0.37	0.0
FINAL, DEG F	32.03	13.56	0.80	32.03	13.56	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	10.70	0.37	0.0	10.70	0.37	0.0
FINAL BOD, MG/L	3.32	13.56	0.80	3.83	13.56	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.48	13.56	0.80	1.55	13.56	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	4.68	0.37	0.0	4.68	0.37	0.0
FINAL BOD, MG/L	2.49	13.56	0.80	2.49	13.56	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	16.04	0.37	0.0	16.21	0.37	0.0
FINAL VALUE, MG/L	7.79	13.56	0.80	7.87	13.56	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	3.42	0.37	0.0	3.42	0.37	0.0
FINAL VALUE, MG/L	1.82	13.56	0.80	1.82	13.56	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.08	0.37	0.0	4.08	0.37	0.0
FINAL VALUE, MG/L	3.00	13.56	0.80	3.00	13.56	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.96	0.37	0.0	4.96	0.37	0.0
FINAL VALUE, MG/L	3.97	13.56	0.80	3.97	13.56	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	15.49	0.37	0.0	15.49	0.37	0.0
FINAL PERCENT	2.49	13.56	0.80	2.49	13.56	0.80


1990 LEVEL.WTR..T.F.
D.O. DAYTIME RESULTS ○
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM


1990 LEVEL.WTR..T.F.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM

E. Computer Results for 1990 Design Level, Trickling Filter and Ames Reservoir, Winter, 10 Yr, High Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4F	COLIE			GAMA1	GAMA2
5.88	50.00	75.00	0.0	44.00	0.080	0.0	20.00	10.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDOD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.300	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDOCY	DLGCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 1.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 9.10 CFS, RIVER Q = 50.00 CFS, TOTAL Q = 59.10 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 0.80 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		50.0	12.79	9.95		0.40
0.0	0.37	34.8	34.8	34.8	59.1	12.08	9.68	10.88	3.42
0.02	0.70	34.5	34.5	34.5	59.1	11.87	9.82	10.85	3.36
0.04	1.03	34.2	34.2	34.2	59.2	11.70	9.93	10.81	3.30
0.06	1.36	34.0	34.0	34.0	59.2	11.57	10.04	10.80	3.25
0.08	1.68	33.7	33.7	33.7	59.2	11.47	10.14	10.80	3.19
0.10	2.01	33.6	33.6	33.6	59.3	11.39	10.24	10.82	3.14
0.12	2.34	33.4	33.4	33.4	59.3	11.34	10.34	10.84	3.09
0.14	2.67	33.2	33.2	33.2	59.3	11.30	10.44	10.87	3.04
0.16	3.00	33.1	33.1	33.1	59.4	11.28	10.53	10.91	2.99
0.18	3.33	33.0	33.0	33.0	59.4	11.27	10.62	10.95	2.94
0.20	3.66	32.9	32.9	32.9	59.4	11.27	10.71	10.99	2.90
0.22	3.99	32.8	32.8	32.8	59.5	11.28	10.79	11.04	2.85
0.24	4.32	32.7	32.7	32.7	59.5	11.30	10.87	11.08	2.81
0.26	4.65	32.6	32.6	32.6	59.5	11.32	10.95	11.13	2.76
0.28	4.97	32.6	32.6	32.6	59.6	11.35	11.02	11.19	2.72
0.30	5.30	32.5	32.5	32.5	59.6	11.38	11.10	11.24	2.68
0.32	5.63	32.4	32.4	32.4	59.6	11.08	10.81	10.95	2.63
0.34	5.96	32.4	32.4	32.4	59.7	10.80	10.53	10.66	2.59
0.36	6.29	32.3	32.3	32.3	59.7	10.53	10.26	10.39	2.55
0.38	6.62	32.3	32.3	32.3	59.7	10.27	10.00	10.13	2.51
0.40	6.95	32.3	32.3	32.3	59.8	10.01	9.75	9.88	2.47
0.42	7.28	32.2	32.2	32.2	59.8	9.77	9.50	9.64	2.44
0.44	7.61	32.2	32.2	32.2	59.8	9.53	9.27	9.40	2.40
0.46	7.94	32.2	32.2	32.2	59.9	9.30	9.04	9.17	2.36
0.48	8.27	32.2	32.2	32.2	59.9	9.08	8.83	8.96	2.33
0.50	8.60	32.2	32.2	32.2	59.9	8.87	8.62	8.75	2.29

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.93	32.1	32.1	32.1	60.0	8.67	8.42	8.54	2.25
0.54	9.26	32.1	32.1	32.1	60.0	8.47	8.22	8.35	2.22
0.56	9.59	32.1	32.1	32.1	60.0	8.28	8.04	8.16	2.19
0.58	9.92	32.1	32.1	32.1	60.1	8.10	7.86	7.98	2.15
0.60	10.25	32.1	32.1	32.1	60.1	7.93	7.69	7.81	2.12
0.62	10.58	32.1	32.1	32.1	60.1	7.76	7.52	7.64	2.09
0.64	10.91	32.1	32.1	32.1	60.2	7.60	7.37	7.48	2.06
0.66	11.24	32.1	32.1	32.1	60.2	7.45	7.21	7.33	2.02
0.68	11.58	32.1	32.1	32.1	60.2	7.30	7.07	7.18	1.99
0.70	11.91	32.0	32.0	32.0	60.3	7.15	6.93	7.04	1.96
0.72	12.24	32.0	32.0	32.0	60.3	7.02	6.79	6.91	1.93
0.74	12.57	32.0	32.0	32.0	60.3	6.89	6.66	6.78	1.90
0.76	12.90	32.0	32.0	32.0	60.4	6.76	6.54	6.65	1.87
0.78	13.23	32.0	32.0	32.0	60.4	6.64	6.42	6.53	1.85
0.80	13.56	32.0	32.0	32.0	60.4	6.52	6.31	6.42	1.82
0.82	13.89	32.0	32.0	32.0	60.5	6.41	6.20	6.31	1.79
0.84	14.22	32.0	32.0	32.0	60.5	6.31	6.10	6.20	1.76
0.86	14.55	32.0	32.0	32.0	60.5	6.21	6.00	6.10	1.74
0.88	14.89	32.0	32.0	32.0	60.6	6.11	5.91	6.01	1.71
0.90	15.22	32.0	32.0	32.0	60.6	6.02	5.81	5.92	1.68
0.92	15.55	32.0	32.0	32.0	60.6	5.93	5.73	5.83	1.66
0.94	15.88	32.0	32.0	32.0	60.7	5.84	5.65	5.75	1.63
0.96	16.21	32.0	32.0	32.0	60.7	5.76	5.57	5.67	1.61
0.98	16.54	32.0	32.0	32.0	60.7	5.69	5.49	5.59	1.58
1.00	16.88	32.0	32.0	32.0	60.8	5.61	5.42	5.52	1.56
1.02	17.21	32.0	32.0	32.0	60.8	5.54	5.35	5.45	1.54

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	17.54	32.0	32.0	32.0	60.8	5.47	5.29	5.38	1.51
1.06	17.87	32.0	32.0	32.0	60.9	5.41	5.23	5.32	1.49
1.08	18.20	32.0	32.0	32.0	60.9	5.35	5.17	5.26	1.47
1.10	18.54	32.0	32.0	32.0	60.9	5.29	5.11	5.20	1.44
1.12	18.87	32.0	32.0	32.0	61.0	5.24	5.06	5.15	1.42
1.14	19.20	32.0	32.0	32.0	61.0	5.18	5.01	5.10	1.40
1.16	19.53	32.0	32.0	32.0	61.0	5.13	4.96	5.05	1.38
1.18	19.87	32.0	32.0	32.0	61.1	5.09	4.92	5.00	1.36
1.20	20.20	32.0	32.0	32.0	61.1	5.04	4.87	4.96	1.34
1.22	20.53	32.0	32.0	32.0	61.1	5.00	4.83	4.92	1.32
1.24	20.86	32.0	32.0	32.0	61.2	4.96	4.79	4.88	1.30
1.26	21.20	32.0	32.0	32.0	61.2	4.92	4.76	4.84	1.28
1.28	21.53	32.0	32.0	32.0	61.2	4.88	4.72	4.80	1.26
1.30	21.86	32.0	32.0	32.0	61.3	4.85	4.69	4.77	1.24
1.32	22.19	32.0	32.0	32.0	61.3	4.82	4.66	4.74	1.22
1.34	22.53	32.0	32.0	32.0	61.3	4.79	4.63	4.71	1.20
1.36	22.86	32.0	32.0	32.0	61.4	4.76	4.60	4.68	1.18
1.38	23.19	32.0	32.0	32.0	61.4	4.73	4.58	4.65	1.17
1.40	23.53	32.0	32.0	32.0	61.4	4.70	4.55	4.63	1.15
1.42	23.86	32.0	32.0	32.0	61.5	4.68	4.53	4.60	1.13
1.44	24.19	32.0	32.0	32.0	61.5	4.65	4.51	4.58	1.11
1.46	24.53	32.0	32.0	32.0	61.5	4.63	4.49	4.56	1.10
1.48	24.86	32.0	32.0	32.0	61.6	4.61	4.47	4.54	1.08
1.50	25.19	32.0	32.0	32.0	61.6	4.59	4.45	4.52	1.06
1.52	25.53	32.0	32.0	32.0	61.6	4.57	4.44	4.50	1.05
1.54	25.86	32.0	32.0	32.0	61.7	4.56	4.42	4.49	1.03

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	26.19	32.0	32.0	32.0	61.7	4.54	4.40	4.47	1.02
1.58	26.53	32.0	32.0	32.0	61.7	4.52	4.39	4.46	1.00
1.60	26.86	32.0	32.0	32.0	61.8	4.51	4.38	4.44	0.99
1.62	27.19	32.0	32.0	32.0	61.8	4.49	4.37	4.43	0.97
1.64	27.53	32.0	32.0	32.0	61.8	4.48	4.35	4.42	0.96
1.66	27.86	32.0	32.0	32.0	61.9	4.47	4.34	4.41	0.94
1.68	28.20	32.0	32.0	32.0	61.9	4.46	4.33	4.39	0.93
1.70	28.53	32.0	32.0	32.0	61.9	4.45	4.32	4.38	0.91
1.72	28.87	32.0	32.0	32.0	62.0	4.43	4.31	4.37	0.90
1.74	29.20	32.0	32.0	32.0	62.0	4.42	4.30	4.36	0.89
1.76	29.53	32.0	32.0	32.0	62.0	4.41	4.30	4.36	0.87
1.78	29.87	32.0	32.0	32.0	62.1	4.40	4.29	4.35	0.86
1.80	30.20	32.0	32.0	32.0	62.1	4.39	4.28	4.34	0.85
1.82	30.54	32.0	32.0	32.0	62.1	4.39	4.27	4.33	0.83
1.84	30.87	32.0	32.0	32.0	62.2	4.38	4.26	4.32	0.82
1.86	31.21	32.0	32.0	32.0	62.2	4.37	4.26	4.31	0.81
1.88	31.54	32.0	32.0	32.0	62.2	4.36	4.25	4.30	0.80
1.90	31.88	32.0	32.0	32.0	62.3	4.35	4.24	4.30	0.78
1.92	32.21	32.0	32.0	32.0	62.3	4.34	4.24	4.29	0.77
1.94	32.55	32.0	32.0	32.0	62.3	4.33	4.23	4.28	0.76
1.96	32.88	32.0	32.0	32.0	62.4	4.32	4.22	4.27	0.75
1.98	33.22	32.0	32.0	32.0	62.4	4.31	4.21	4.26	0.74

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.66	2.66	0.55	3.21	3.00	0.40	0.10
0.0	0.37	10.70	0.75	11.45	4.68	16.13	4.08	4.96	15.49
0.02	0.70	10.43	0.77	11.20	4.60	15.80	4.04	4.93	14.75
0.04	1.03	10.13	0.79	10.92	4.52	15.44	4.00	4.90	14.06
0.06	1.36	9.85	0.81	10.65	4.44	15.10	3.96	4.87	13.41
0.08	1.68	9.57	0.83	10.40	4.37	14.77	3.92	4.84	12.79
0.10	2.01	9.30	0.85	10.15	4.30	14.45	3.88	4.81	12.20
0.12	2.34	9.05	0.87	9.91	4.23	14.14	3.85	4.79	11.64
0.14	2.67	8.80	0.89	9.68	4.16	13.84	3.81	4.76	11.11
0.16	3.00	8.56	0.91	9.46	4.09	13.56	3.77	4.73	10.61
0.18	3.33	8.33	0.92	9.25	4.03	13.28	3.74	4.70	10.13
0.20	3.66	8.11	0.94	9.05	3.96	13.01	3.70	4.68	9.67
0.22	3.99	7.89	0.96	8.85	3.90	12.75	3.67	4.65	9.24
0.24	4.32	7.68	0.98	8.67	3.84	12.50	3.63	4.62	8.82
0.26	4.65	7.48	1.00	8.48	3.78	12.26	3.60	4.60	8.43
0.28	4.97	7.29	1.02	8.31	3.72	12.03	3.57	4.57	8.05
0.30	5.30	7.10	1.04	8.14	3.66	11.80	3.53	4.55	7.70
0.32	5.63	6.92	1.06	7.98	3.60	11.58	3.50	4.52	7.35
0.34	5.96	6.74	1.08	7.82	3.55	11.37	3.46	4.50	7.03
0.36	6.29	6.57	1.10	7.67	3.49	11.16	3.43	4.47	6.72
0.38	6.62	6.40	1.12	7.52	3.44	10.96	3.40	4.45	6.42
0.40	6.95	6.24	1.14	7.38	3.39	10.76	3.37	4.42	6.13
0.42	7.28	6.08	1.16	7.24	3.33	10.57	3.33	4.40	5.86
0.44	7.61	5.93	1.17	7.11	3.28	10.39	3.30	4.38	5.60
0.46	7.94	5.79	1.19	6.98	3.23	10.21	3.27	4.35	5.36
0.48	8.27	5.64	1.21	6.85	3.18	10.04	3.24	4.33	5.12
0.50	8.60	5.50	1.23	6.74	3.13	9.87	3.21	4.30	4.90

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.93	5.37	1.25	6.62	3.08	9.70	3.18	4.28	4.68
0.54	9.26	5.24	1.27	6.51	3.04	9.54	3.15	4.26	4.47
0.56	9.59	5.11	1.29	6.40	2.99	9.39	3.12	4.23	4.28
0.58	9.92	4.99	1.31	6.29	2.94	9.24	3.09	4.21	4.09
0.60	10.25	4.87	1.33	6.19	2.90	9.09	3.06	4.19	3.91
0.62	10.58	4.75	1.35	6.09	2.86	8.95	3.03	4.16	3.74
0.64	10.91	4.63	1.36	6.00	2.81	8.81	3.00	4.14	3.57
0.66	11.24	4.52	1.38	5.91	2.77	8.68	3.00	4.12	3.42
0.68	11.58	4.42	1.40	5.82	2.73	8.55	3.00	4.10	3.27
0.70	11.91	4.31	1.42	5.73	2.68	8.42	3.00	4.07	3.12
0.72	12.24	4.21	1.44	5.65	2.64	8.29	3.00	4.05	2.99
0.74	12.57	4.11	1.46	5.57	2.60	8.17	3.00	4.03	2.85
0.76	12.90	4.01	1.48	5.49	2.56	8.06	3.00	4.01	2.73
0.78	13.23	3.92	1.50	5.42	2.52	7.94	3.00	3.99	2.61
0.80	13.56	3.83	1.52	5.34	2.49	7.83	3.00	3.97	2.49
0.82	13.89	3.74	1.53	5.27	2.45	7.72	3.00	3.94	2.39
0.84	14.22	3.65	1.55	5.21	2.41	7.62	3.00	3.92	2.28
0.86	14.55	3.57	1.57	5.14	2.37	7.51	3.00	3.90	2.18
0.88	14.89	3.49	1.59	5.08	2.34	7.41	3.00	3.88	2.08
0.90	15.22	3.41	1.61	5.02	2.30	7.32	3.00	3.86	1.99
0.92	15.55	3.33	1.63	4.96	2.27	7.22	3.00	3.84	1.91
0.94	15.88	3.25	1.65	4.90	2.23	7.13	3.00	3.82	1.82
0.96	16.21	3.18	1.67	4.84	2.20	7.04	3.00	3.80	1.74
0.98	16.54	3.11	1.68	4.79	2.17	6.96	3.00	3.78	1.67
1.00	16.88	3.04	1.70	4.74	2.13	6.87	3.00	3.76	1.59
1.02	17.21	2.97	1.72	4.69	2.10	6.79	3.00	3.74	1.52

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	17.54	2.90	1.74	4.64	2.07	6.71	3.00	3.71	1.46
1.06	17.87	2.83	1.76	4.59	2.04	6.63	3.00	3.69	1.39
1.08	18.20	2.77	1.78	4.55	2.01	6.55	3.00	3.67	1.33
1.10	18.54	2.71	1.80	4.51	1.98	6.48	3.00	3.65	1.27
1.12	18.87	2.65	1.81	4.46	1.95	6.41	3.00	3.63	1.22
1.14	19.20	2.59	1.83	4.42	1.92	6.34	3.00	3.62	1.16
1.16	19.53	2.53	1.85	4.38	1.89	6.27	3.00	3.60	1.11
1.18	19.87	2.48	1.87	4.35	1.86	6.21	3.00	3.58	1.06
1.20	20.20	2.42	1.89	4.31	1.83	6.14	3.00	3.56	1.02
1.22	20.53	2.37	1.91	4.28	1.80	6.08	3.00	3.54	0.97
1.24	20.86	2.32	1.93	4.24	1.77	6.02	3.00	3.52	0.93
1.26	21.20	2.27	1.95	4.21	1.75	5.96	3.00	3.50	0.89
1.28	21.53	2.22	1.96	4.18	1.72	5.90	3.00	3.48	0.85
1.30	21.86	2.17	1.98	4.15	1.70	5.85	3.00	3.46	0.81
1.32	22.19	2.12	2.00	4.12	1.67	5.79	3.00	3.44	0.78
1.34	22.53	2.07	2.02	4.09	1.64	5.74	3.00	3.42	0.74
1.36	22.86	2.03	2.04	4.07	1.62	5.69	3.00	3.41	0.71
1.38	23.19	1.99	2.06	4.04	1.59	5.64	3.00	3.39	0.68
1.40	23.53	1.94	2.08	4.02	1.57	5.59	3.00	3.37	0.65
1.42	23.86	1.90	2.09	4.00	1.55	5.54	3.00	3.35	0.62
1.44	24.19	1.86	2.11	3.97	1.52	5.50	3.00	3.33	0.59
1.46	24.53	1.82	2.13	3.95	1.50	5.45	3.00	3.31	0.57
1.48	24.86	1.78	2.15	3.93	1.48	5.41	3.00	3.30	0.54
1.50	25.19	1.74	2.17	3.91	1.46	5.37	3.00	3.28	0.52
1.52	25.53	1.70	2.19	3.89	1.43	5.33	3.00	3.26	0.50
1.54	25.86	1.67	2.21	3.87	1.41	5.29	3.00	3.24	0.48

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	26.19	1.63	2.23	3.86	1.39	5.25	3.00	3.23	0.45
1.58	26.53	1.60	2.24	3.84	1.37	5.21	3.00	3.21	0.43
1.60	26.86	1.56	2.26	3.83	1.35	5.17	3.00	3.19	0.42
1.62	27.19	1.53	2.28	3.81	1.33	5.14	3.00	3.17	0.40
1.64	27.53	1.50	2.30	3.80	1.31	5.11	3.00	3.16	0.38
1.66	27.86	1.47	2.32	3.78	1.29	5.07	3.00	3.14	0.36
1.68	28.20	1.44	2.34	3.77	1.27	5.04	3.00	3.12	0.35
1.70	28.53	1.41	2.36	3.76	1.25	5.01	3.00	3.11	0.33
1.72	28.87	1.38	2.37	3.75	1.23	4.98	3.00	3.09	0.32
1.74	29.20	1.35	2.39	3.74	1.21	4.95	3.00	3.07	0.30
1.76	29.53	1.32	2.41	3.73	1.19	4.92	3.00	3.06	0.29
1.78	29.87	1.29	2.43	3.72	1.18	4.90	3.00	3.04	0.28
1.80	30.20	1.26	2.45	3.71	1.16	4.87	3.00	3.02	0.27
1.82	30.54	1.24	2.47	3.70	1.14	4.84	3.00	3.01	0.25
1.84	30.87	1.21	2.48	3.70	1.12	4.82	3.00	2.99	0.24
1.86	31.21	1.19	2.50	3.69	1.11	4.79	3.00	2.97	0.23
1.88	31.54	1.16	2.52	3.68	1.09	4.77	3.00	2.96	0.22
1.90	31.88	1.14	2.54	3.68	1.07	4.75	3.00	2.94	0.21
1.92	32.21	1.11	2.56	3.67	1.06	4.73	3.00	2.93	0.20
1.94	32.55	1.09	2.58	3.67	1.04	4.71	3.00	2.91	0.19
1.96	32.88	1.07	2.59	3.66	1.03	4.69	3.00	2.89	0.19
1.98	33.22	1.05	2.61	3.66	1.01	4.67	3.00	2.88	0.18

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	12.08	0.37	0.0	9.68	0.37	0.0
MINIMUM DO, MG/L	4.31	33.22	1.98	4.21	33.22	1.98
FINAL DO, MG/L	6.52	13.56	0.80	6.31	13.56	0.80
DO DEFICIT						
INITIAL, MG/L	1.53	0.37	0.0	3.94	0.37	0.0
FINAL, MG/L	7.68	13.56	0.80	7.90	13.56	0.80
RIVER DISCHARGE						
INITIAL, CFS	59.10	0.37	0.0	59.10	0.37	0.0
FINAL, CFS	60.42	13.56	0.80	60.42	13.56	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	34.77	0.37	0.0	34.77	0.37	0.0
FINAL, DEG F	32.03	13.56	0.80	32.03	13.56	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	10.70	0.37	0.0	10.70	0.37	0.0
FINAL BOD, MG/L	3.82	13.56	0.80	3.83	13.56	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.48	13.56	0.80	1.55	13.56	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	4.68	0.37	0.0	4.68	0.37	0.0
FINAL BOD, MG/L	2.49	13.56	0.80	2.49	13.56	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	16.04	0.37	0.0	16.21	0.37	0.0
FINAL VALUE, MG/L	7.79	13.56	0.80	7.87	13.56	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	3.42	0.37	0.0	3.42	0.37	0.0
FINAL VALUE, MG/L	1.82	13.56	0.80	1.82	13.56	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	4.08	0.37	0.0	4.08	0.37	0.0
FINAL VALUE, MG/L	3.00	13.56	0.80	3.00	13.56	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.96	0.37	0.0	4.96	0.37	0.0
FINAL VALUE, MG/L	3.97	13.56	0.80	3.97	13.56	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	15.49	0.37	0.0	15.49	0.37	0.0
FINAL PERCENT	2.49	13.56	0.80	2.49	13.56	0.80

F. Computer Results for 1990 Design Level,

Activated Sludge and Ames Reservoir, August, 10 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
7.19	70.00	25.00	0.0	12.00	0.080	0.0	20.00	5.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
88.00	73.00	120.00	75.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	50.00	2.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.60	105.00	60.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
88.00	73.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	2.00	3.00	3.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 50.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 2.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 11.13 CFS, RIVER Q = 50.00 CFS, TOTAL Q = 61.13 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 1.00 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	88.0	73.0		50.0	8.48	6.21		0.40
0.0	0.37	84.7	72.5	78.6	61.1	7.32	5.47	6.40	3.97
0.01	0.54	84.9	72.5	78.7	61.2	6.85	5.13	5.99	3.74
0.02	0.70	85.1	72.5	78.8	61.3	6.48	4.83	5.65	3.53
0.03	0.87	85.2	72.5	78.9	61.4	6.21	4.57	5.39	3.32
0.04	1.04	85.4	72.6	79.0	61.5	6.03	4.35	5.19	3.13
0.05	1.20	85.5	72.6	79.1	61.6	5.93	4.17	5.05	2.95
0.06	1.37	85.7	72.6	79.1	61.7	5.90	4.00	4.95	2.78
0.07	1.54	85.8	72.6	79.2	61.8	5.93	3.86	4.90	2.62
0.08	1.70	85.9	72.7	79.3	61.9	6.02	3.73	4.88	2.47
0.09	1.87	86.0	72.7	79.4	62.0	6.16	3.62	4.89	2.33
0.10	2.04	86.2	72.7	79.4	62.1	6.35	3.52	4.93	2.19
0.11	2.20	86.3	72.7	79.5	62.2	6.57	3.42	5.00	2.07
0.12	2.37	86.4	72.7	79.5	62.3	6.83	3.34	5.08	1.95
0.13	2.54	86.4	72.7	79.6	62.4	7.11	3.26	5.19	1.84
0.14	2.71	86.5	72.8	79.6	62.5	7.42	3.20	5.31	1.74
0.15	2.88	86.6	72.8	79.7	62.6	7.75	3.13	5.44	1.64
0.16	3.04	86.7	72.8	79.7	62.7	8.09	3.08	5.59	1.55
0.17	3.21	86.8	72.8	79.8	62.8	8.44	3.04	5.74	1.46
0.18	3.38	86.8	72.8	79.8	62.9	8.79	3.00	5.89	1.38
0.19	3.55	86.9	72.8	79.9	63.0	9.14	2.96	6.05	1.30
0.20	3.72	87.0	72.8	79.9	63.1	9.49	2.94	6.21	1.23
0.21	3.88	87.0	72.8	79.9	63.2	9.83	2.92	6.37	1.16
0.22	4.05	87.1	72.8	80.0	63.3	10.15	2.90	6.53	1.10
0.23	4.22	87.1	72.9	80.0	63.4	10.46	2.90	6.68	1.04
0.24	4.39	87.2	72.9	80.0	63.5	10.75	2.89	6.82	0.98
0.25	4.56	87.2	72.9	80.0	63.6	11.01	2.90	6.96	0.93

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	4.73	87.3	72.9	80.1	63.7	11.25	2.91	7.08	0.88
0.27	4.90	87.3	72.9	80.1	63.8	11.46	2.92	7.19	0.83
0.28	5.06	87.3	72.9	80.1	63.9	11.65	2.94	7.29	0.79
0.29	5.23	87.4	72.9	80.1	64.0	11.79	2.97	7.38	0.75
0.30	5.40	87.4	72.9	80.2	64.1	11.91	3.00	7.45	0.72
0.31	5.57	87.4	72.9	80.2	64.3	12.00	3.03	7.51	0.70
0.32	5.74	87.5	72.9	80.2	64.4	12.05	3.08	7.56	0.68
0.33	5.91	87.5	72.9	80.2	64.5	12.06	3.12	7.59	0.66
0.34	6.08	87.5	72.9	80.2	64.6	12.05	3.18	7.61	0.64
0.35	6.25	87.6	72.9	80.2	64.7	12.01	3.24	7.62	0.62
0.36	6.42	87.6	72.9	80.3	64.8	11.93	3.30	7.62	0.60
0.37	6.59	87.6	72.9	80.3	64.9	11.83	3.37	7.60	0.58
0.38	6.76	87.6	72.9	80.3	65.0	11.71	3.45	7.58	0.57
0.39	6.93	87.7	72.9	80.3	65.1	11.56	3.53	7.55	0.55
0.40	7.10	87.7	72.9	80.3	65.2	11.40	3.63	7.51	0.54
0.41	7.27	87.7	72.9	80.3	65.3	11.22	3.72	7.47	0.52
0.42	7.44	87.7	73.0	80.3	65.4	11.03	3.83	7.43	0.51
0.43	7.61	87.7	73.0	80.3	65.5	10.83	3.94	7.38	0.49
0.44	7.78	87.7	73.0	80.3	65.6	10.63	4.05	7.34	0.48
0.45	7.95	87.8	73.0	80.4	65.7	10.43	4.17	7.30	0.47
0.46	8.12	87.8	73.0	80.4	65.8	10.23	4.29	7.26	0.46
0.47	8.30	87.8	73.0	80.4	65.9	10.04	4.41	7.22	0.45
0.48	8.47	87.8	73.0	80.4	66.0	9.85	4.53	7.19	0.44
0.49	8.64	87.8	73.0	80.4	66.1	9.69	4.65	7.17	0.43
0.50	8.81	87.8	73.0	80.4	66.2	9.54	4.76	7.15	0.42
0.51	8.98	87.8	73.0	80.4	66.3	9.40	4.86	7.13	0.41

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	9.15	87.8	73.0	80.4	66.4	9.29	4.95	7.12	0.40
0.53	9.32	87.8	73.0	80.4	66.5	9.20	5.04	7.12	0.40
0.54	9.49	87.9	73.0	80.4	66.6	9.12	5.11	7.11	0.40
0.55	9.67	87.9	73.0	80.4	66.7	9.05	5.18	7.11	0.40
0.56	9.84	87.9	73.0	80.4	66.8	8.99	5.24	7.11	0.40
0.57	10.01	87.9	73.0	80.4	66.9	8.94	5.30	7.12	0.40
0.58	10.18	87.9	73.0	80.4	67.0	8.90	5.35	7.12	0.40
0.59	10.35	87.9	73.0	80.4	67.1	8.86	5.40	7.13	0.40
0.60	10.53	87.9	73.0	80.4	67.2	8.83	5.44	7.13	0.40
0.61	10.70	87.9	73.0	80.4	67.3	8.80	5.48	7.14	0.40
0.62	10.87	87.9	73.0	80.4	67.4	8.78	5.52	7.15	0.40
0.63	11.04	87.9	73.0	80.4	67.5	8.76	5.55	7.16	0.40
0.64	11.22	87.9	73.0	80.5	67.6	8.75	5.58	7.16	0.40
0.65	11.39	87.9	73.0	80.5	67.7	8.74	5.61	7.17	0.40
0.66	11.56	87.9	73.0	80.5	67.8	8.73	5.64	7.18	0.40
0.67	11.74	87.9	73.0	80.5	67.9	8.72	5.66	7.19	0.40
0.68	11.91	87.9	73.0	80.5	68.1	8.71	5.68	7.20	0.40
0.69	12.08	87.9	73.0	80.5	68.2	8.70	5.70	7.20	0.40
0.70	12.25	87.9	73.0	80.5	68.3	8.70	5.72	7.21	0.40
0.71	12.43	87.9	73.0	80.5	68.4	8.69	5.74	7.22	0.40
0.72	12.60	87.9	73.0	80.5	68.5	8.69	5.76	7.22	0.40
0.73	12.77	88.0	73.0	80.5	68.6	8.69	5.77	7.23	0.40
0.74	12.95	88.0	73.0	80.5	68.7	8.69	5.79	7.24	0.40
0.75	13.12	88.0	73.0	80.5	68.8	8.68	5.80	7.24	0.40
0.76	13.30	88.0	73.0	80.5	68.9	8.68	5.81	7.25	0.40
0.77	13.47	88.0	73.0	80.5	69.0	8.68	5.82	7.25	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	13.64	88.0	73.0	80.5	69.1	8.68	5.83	7.26	0.40
0.79	13.82	88.0	73.0	80.5	69.2	8.68	5.85	7.26	0.40
0.80	13.99	88.0	73.0	80.5	69.3	8.68	5.85	7.27	0.40
0.81	14.17	88.0	73.0	80.5	69.4	8.68	5.86	7.27	0.40
0.82	14.34	88.0	73.0	80.5	69.5	8.68	5.87	7.28	0.40
0.83	14.52	88.0	73.0	80.5	69.6	8.68	5.88	7.28	0.40
0.84	14.69	88.0	73.0	80.5	69.7	8.68	5.89	7.28	0.40
0.85	14.86	88.0	73.0	80.5	69.8	8.68	5.90	7.29	0.40
0.86	15.04	88.0	73.0	80.5	69.9	8.68	5.90	7.29	0.40
0.87	15.21	88.0	73.0	80.5	70.0	8.68	5.91	7.30	0.40
0.88	15.39	88.0	73.0	80.5	70.1	8.68	5.91	7.30	0.40
0.89	15.56	88.0	73.0	80.5	70.2	8.68	5.92	7.30	0.40
0.90	15.74	88.0	73.0	80.5	70.4	8.68	5.93	7.30	0.40
0.91	15.91	88.0	73.0	80.5	70.5	8.68	5.93	7.31	0.40
0.92	16.09	88.0	73.0	80.5	70.6	8.68	5.94	7.31	0.40
0.93	16.27	88.0	73.0	80.5	70.7	8.68	5.94	7.31	0.40
0.94	16.44	88.0	73.0	80.5	70.8	8.68	5.94	7.31	0.40
0.95	16.62	88.0	73.0	80.5	70.9	8.68	5.95	7.32	0.40
0.96	16.79	88.0	73.0	80.5	71.0	8.68	5.95	7.32	0.40
0.97	16.97	88.0	73.0	80.5	71.1	8.68	5.96	7.32	0.40
0.98	17.14	88.0	73.0	80.5	71.2	8.68	5.96	7.32	0.40
0.99	17.32	88.0	73.0	80.5	71.3	8.68	5.96	7.32	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.85	2.85	0.55	3.40	3.00	0.40	0.10
0.0	0.37	4.54	1.10	5.64	5.43	11.07	3.36	4.88	18.29
0.01	0.54	4.38	1.09	5.47	5.12	10.59	3.29	4.78	16.84
0.02	0.70	4.20	1.08	5.27	4.82	10.10	3.21	4.68	15.51
0.03	0.87	4.02	1.06	5.09	4.54	9.63	3.12	4.59	14.28
0.04	1.04	3.86	1.05	4.91	4.28	9.19	3.06	4.50	13.14
0.05	1.20	3.70	1.04	4.74	4.04	8.77	3.03	4.40	12.10
0.06	1.37	3.55	1.03	4.58	3.80	8.38	3.00	4.31	11.14
0.07	1.54	3.41	1.02	4.42	3.58	8.01	3.00	4.22	10.26
0.08	1.70	3.27	1.01	4.28	3.38	7.66	3.00	4.14	9.45
0.09	1.87	3.14	1.00	4.14	3.18	7.33	3.00	4.05	8.70
0.10	2.04	3.02	0.99	4.01	3.00	7.01	3.00	3.97	8.01
0.11	2.20	2.91	0.98	3.89	2.83	6.72	3.00	3.89	7.38
0.12	2.37	2.79	0.98	3.77	2.67	6.44	3.00	3.81	6.79
0.13	2.54	2.69	0.97	3.66	2.52	6.18	3.00	3.73	6.26
0.14	2.71	2.59	0.97	3.55	2.37	5.93	3.00	3.65	5.77
0.15	2.88	2.49	0.96	3.45	2.24	5.69	3.00	3.57	5.31
0.16	3.04	2.40	0.96	3.36	2.11	5.47	3.00	3.50	4.90
0.17	3.21	2.31	0.95	3.26	2.00	5.26	3.00	3.43	4.51
0.18	3.38	2.23	0.95	3.18	1.88	5.06	3.00	3.36	4.16
0.19	3.55	2.15	0.95	3.09	1.78	4.87	3.00	3.29	3.83
0.20	3.72	2.07	0.95	3.02	1.68	4.70	3.00	3.22	3.54
0.21	3.88	2.00	0.95	2.94	1.59	4.53	3.00	3.15	3.26
0.22	4.05	1.92	0.94	2.87	1.50	4.37	3.00	3.09	3.01
0.23	4.22	1.86	0.94	2.80	1.42	4.22	3.00	3.02	2.78
0.24	4.39	1.79	0.94	2.74	1.34	4.08	3.00	2.96	2.56
0.25	4.56	1.73	0.94	2.67	1.27	3.94	3.00	2.90	2.36

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	4.73	1.67	0.94	2.62	1.20	3.82	3.00	2.84	2.18
0.27	4.90	1.62	0.94	2.56	1.14	3.70	3.00	2.78	2.02
0.28	5.06	1.56	0.95	2.51	1.08	3.58	3.00	2.72	1.86
0.29	5.23	1.51	0.95	2.46	1.02	3.47	3.00	2.67	1.72
0.30	5.40	1.46	0.95	2.41	0.96	3.37	3.00	2.61	1.59
0.31	5.57	1.41	0.95	2.36	0.91	3.27	3.00	2.56	1.47
0.32	5.74	1.36	0.95	2.32	0.87	3.18	3.00	2.51	1.36
0.33	5.91	1.32	0.95	2.27	0.82	3.09	3.00	2.45	1.26
0.34	6.08	1.28	0.96	2.23	0.78	3.01	3.00	2.40	1.16
0.35	6.25	1.24	0.96	2.20	0.74	2.93	3.00	2.36	1.07
0.36	6.42	1.20	0.96	2.16	0.70	2.86	3.00	2.31	0.99
0.37	6.59	1.16	0.97	2.12	0.66	2.79	3.00	2.26	0.92
0.38	6.76	1.12	0.97	2.09	0.63	2.72	3.00	2.21	0.85
0.39	6.93	1.09	0.97	2.06	0.60	2.66	3.00	2.17	0.79
0.40	7.10	1.05	0.98	2.03	0.57	2.60	3.00	2.13	0.73
0.41	7.27	1.02	0.98	2.00	0.54	2.54	3.00	2.08	0.68
0.42	7.44	0.99	0.98	1.97	0.51	2.49	3.00	2.04	0.63
0.43	7.61	0.96	0.99	1.94	0.49	2.43	3.00	2.00	0.58
0.44	7.78	0.93	0.99	1.92	0.46	2.38	3.00	1.96	0.54
0.45	7.95	0.90	1.00	1.90	0.44	2.34	3.00	1.92	0.50
0.46	8.12	0.87	1.00	1.87	0.42	2.29	3.00	1.88	0.46
0.47	8.30	0.84	1.01	1.85	0.40	2.25	3.00	1.84	0.43
0.48	8.47	0.82	1.01	1.83	0.38	2.21	3.00	1.81	0.40
0.49	8.64	0.79	1.02	1.81	0.36	2.17	3.00	1.77	0.37
0.50	8.81	0.77	1.02	1.79	0.35	2.14	3.00	1.73	0.34
0.51	8.98	0.75	1.03	1.77	0.33	2.10	3.00	1.70	0.32

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES; WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	9.15	0.73	1.03	1.76	0.31	2.07	3.00	1.67	0.30
0.53	9.32	0.70	1.04	1.74	0.30	2.04	3.00	1.63	0.28
0.54	9.49	0.68	1.04	1.72	0.29	2.01	3.00	1.60	0.27
0.55	9.67	0.66	1.05	1.71	0.27	1.98	3.00	1.57	0.25
0.56	9.84	0.64	1.05	1.69	0.26	1.95	3.00	1.54	0.24
0.57	10.01	0.62	1.06	1.68	0.25	1.93	3.00	1.51	0.23
0.58	10.18	0.61	1.06	1.67	0.24	1.90	3.00	1.48	0.21
0.59	10.35	0.59	1.07	1.66	0.23	1.88	3.00	1.45	0.20
0.60	10.53	0.57	1.07	1.64	0.22	1.86	3.00	1.42	0.19
0.61	10.70	0.56	1.08	1.63	0.21	1.84	3.00	1.39	0.18
0.62	10.87	0.54	1.08	1.62	0.20	1.82	3.00	1.37	0.17
0.63	11.04	0.52	1.09	1.61	0.19	1.80	3.00	1.34	0.17
0.64	11.22	0.51	1.09	1.60	0.18	1.78	3.00	1.31	0.16
0.65	11.39	0.49	1.10	1.59	0.17	1.77	3.00	1.29	0.15
0.66	11.56	0.48	1.11	1.59	0.17	1.75	3.00	1.26	0.14
0.67	11.74	0.47	1.11	1.58	0.16	1.74	3.00	1.24	0.14
0.68	11.91	0.45	1.12	1.57	0.15	1.72	3.00	1.22	0.13
0.69	12.08	0.44	1.12	1.56	0.14	1.71	3.00	1.19	0.13
0.70	12.25	0.43	1.13	1.56	0.14	1.69	3.00	1.17	0.12
0.71	12.43	0.42	1.13	1.55	0.13	1.68	3.00	1.15	0.12
0.72	12.60	0.40	1.14	1.54	0.13	1.67	3.00	1.13	0.11
0.73	12.77	0.39	1.14	1.54	0.12	1.66	3.00	1.10	0.11
0.74	12.95	0.38	1.15	1.53	0.12	1.65	3.00	1.08	0.10
0.75	13.12	0.37	1.16	1.53	0.11	1.64	3.00	1.06	0.10
0.76	13.30	0.36	1.16	1.52	0.11	1.63	3.00	1.04	0.10
0.77	13.47	0.35	1.17	1.52	0.10	1.62	3.00	1.02	0.10

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

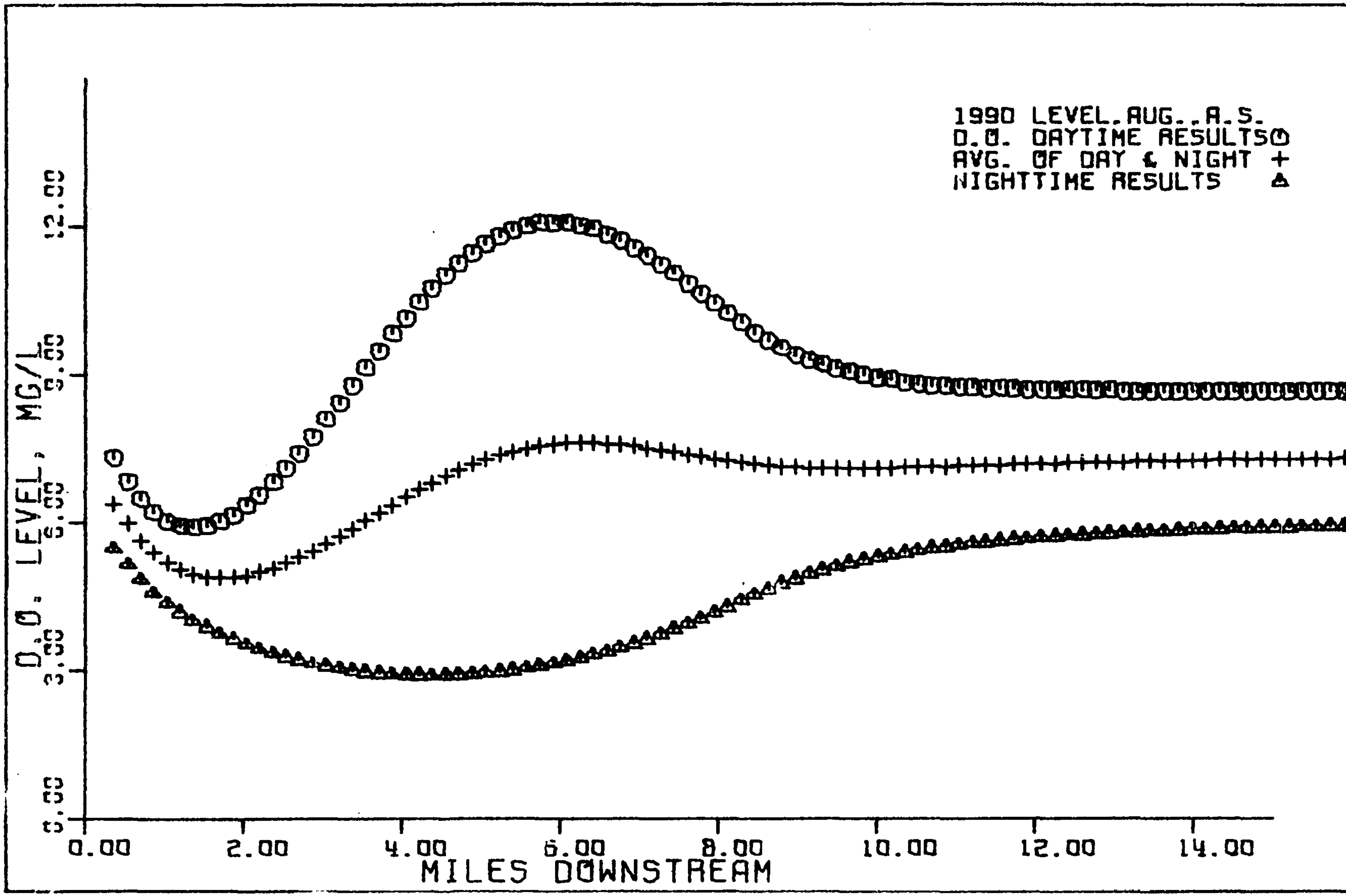
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	13.64	0.34	1.17	1.51	0.10	1.61	3.00	1.00	0.10
0.79	13.82	0.33	1.18	1.51	0.10	1.61	3.00	0.99	0.10
0.80	13.99	0.32	1.18	1.51	0.09	1.60	3.00	0.97	0.10
0.81	14.17	0.31	1.19	1.50	0.09	1.59	3.00	0.95	0.10
0.82	14.34	0.30	1.20	1.50	0.08	1.59	3.00	0.93	0.10
0.83	14.52	0.30	1.20	1.50	0.08	1.58	3.00	0.91	0.10
0.84	14.69	0.29	1.21	1.50	0.08	1.57	3.00	0.90	0.10
0.85	14.86	0.28	1.21	1.49	0.08	1.57	3.00	0.88	0.10
0.86	15.04	0.27	1.22	1.49	0.07	1.56	3.00	0.87	0.10
0.87	15.21	0.26	1.22	1.49	0.07	1.56	3.00	0.85	0.10
0.88	15.39	0.26	1.23	1.49	0.07	1.55	3.00	0.83	0.10
0.89	15.56	0.25	1.24	1.49	0.07	1.55	3.00	0.82	0.10
0.90	15.74	0.24	1.24	1.48	0.06	1.55	3.00	0.80	0.10
0.91	15.91	0.24	1.25	1.48	0.06	1.54	3.00	0.79	0.10
0.92	16.09	0.23	1.25	1.48	0.06	1.54	3.00	0.78	0.10
0.93	16.27	0.22	1.26	1.48	0.06	1.54	3.00	0.77	0.10
0.94	16.44	0.22	1.26	1.48	0.05	1.54	3.00	0.77	0.10
0.95	16.62	0.21	1.27	1.48	0.05	1.53	3.00	0.76	0.10
0.96	16.79	0.21	1.27	1.48	0.05	1.53	3.00	0.75	0.10
0.97	16.97	0.20	1.28	1.48	0.05	1.53	3.00	0.74	0.10
0.98	17.14	0.20	1.28	1.48	0.05	1.53	3.00	0.73	0.10
0.99	17.32	0.19	1.29	1.48	0.05	1.53	3.00	0.72	0.10

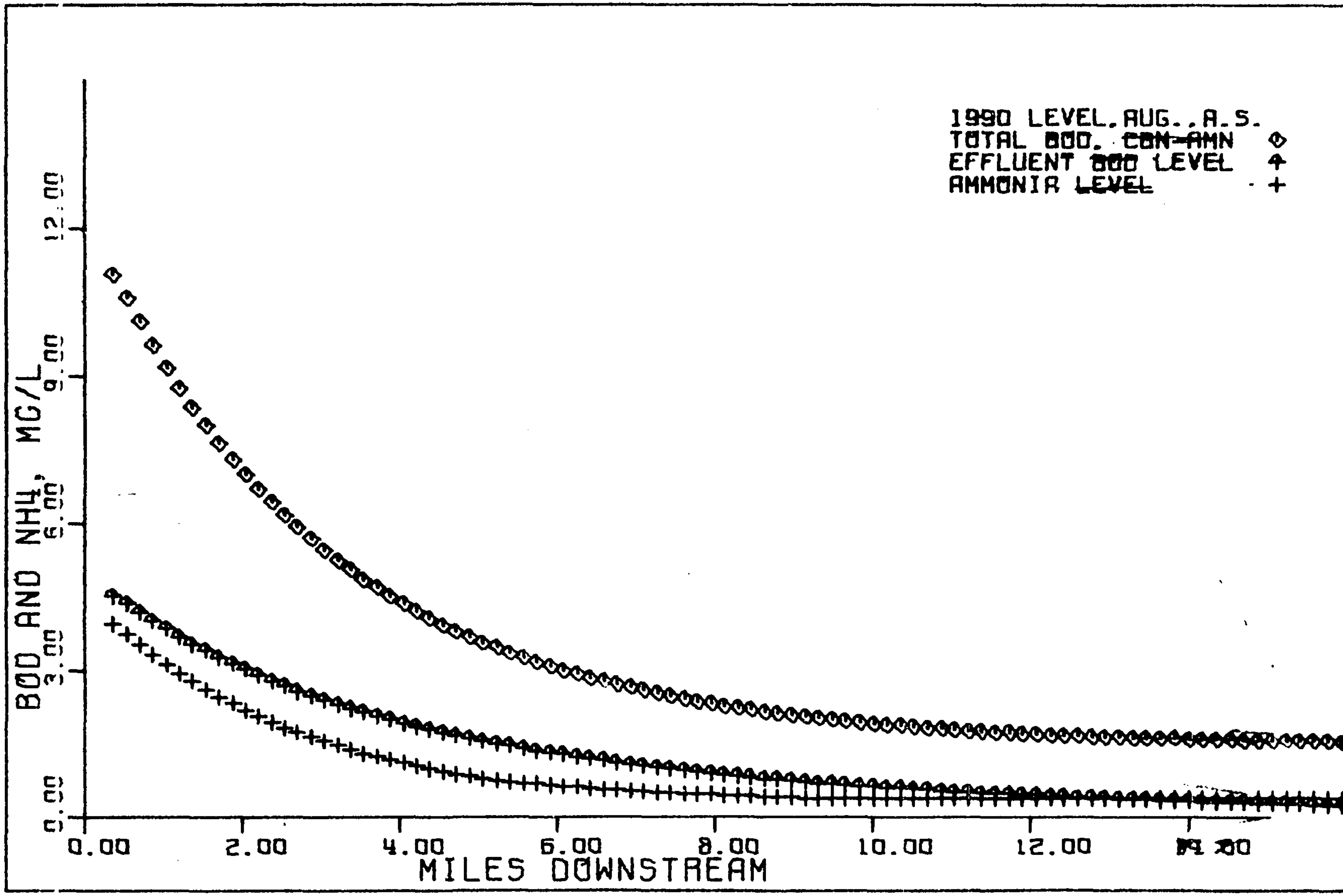
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : AUGUST
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	7.32	0.37	0.0	5.47	0.37	0.0
MINIMUM DO, MG/L	5.90	1.37	0.06	2.89	4.39	0.24
FINAL DO, MG/L	8.68	13.99	0.80	5.85	13.99	0.80
DO DEFICIT						
INITIAL, MG/L	-0.01	0.37	0.0	2.86	0.37	0.0
FINAL, MG/L	-1.62	13.99	0.80	2.42	13.99	0.80
RIVER DISCHARGE						
INITIAL, CFS	61.13	0.37	0.0	61.13	0.37	0.0
FINAL, CFS	69.30	13.99	0.80	69.30	13.99	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	84.72	0.37	0.0	72.45	0.37	0.0
FINAL, DEG F	87.97	13.99	0.80	72.99	13.99	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	4.54	0.37	0.0	4.54	0.37	0.0
FINAL BOD, MG/L	0.21	13.99	0.80	0.43	13.99	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.03	0.37	0.0	0.03	0.37	0.0
FINAL BOD IN RIVER	1.04	13.99	0.80	1.33	13.99	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	5.43	0.37	0.0	5.43	0.37	0.0
FINAL BOD, MG/L	0.02	13.99	0.80	0.17	13.99	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	10.82	0.37	0.0	11.31	0.37	0.0
FINAL VALUE, MG/L	1.27	13.99	0.80	1.93	13.99	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	3.97	0.37	0.0	3.97	0.37	0.0
FINAL VALUE, MG/L	0.40	13.99	0.80	0.40	13.99	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.36	0.37	0.0	3.36	0.37	0.0
FINAL VALUE, MG/L	3.00	13.99	0.80	3.00	13.99	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.88	0.37	0.0	4.88	0.37	0.0
FINAL VALUE, MG/L	0.53	13.99	0.80	1.40	13.99	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	18.29	0.37	0.0	18.29	0.37	0.0
FINAL PERCENT	0.10	13.99	0.80	0.10	13.99	0.80


1990 LEVEL.AUG..A.S.
D.O. DAYTIME RESULTS ⊙
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS △
D.O. LEVEL, MG/L
12.00
9.00
6.00
3.00
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


1990 LEVEL, AUG., A.S.
TOTAL BOD, CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
MILES DOWNSTREAM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00

G. Computer Results for 1990 Design Level, Activated Sludge and Ames Reservoir, September, 10 Yr

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : SEPT.

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
7.19	65.00	25.00	0.0	12.00	0.080	0.0	20.00	5.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
83.00	68.00	125.00	70.00	2.50	0.140	0.0	0.40	3.00	0.40	0.10	60.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.30	110.00	55.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
83.00	68.00	2.500	0.0	0.0	3.000	0.100	0.40	1.20	1.60	2.50	2.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

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              AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

    INPUT DATA FOR THIS ANALYSIS

    STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
    RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
    SEASON : SEPT.

 GAMMA1 =    0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
   OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
   CYCLE NO.  1
   BANK LOAD IS    60.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
       ADDITIONAL BANK LOAD DOWNSTREAM IS   3.00 LBS/DAY/MILE
   FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
       EFFLUENT Q =  11.13 CFS, RIVER Q =  50.00 CFS, TOTAL Q =  61.13 CFS
       CYCLE INCREMENT IS  0.0  CFS
   FOR ALGAE VARIATIONS, P-MINUS-R =   1.20 MG/L/HR
       CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	83.0	68.0		50.0	9.31	6.13		0.40
0.0	0.37	79.7	67.5	73.6	61.1	8.02	5.42	6.72	3.97
0.01	0.54	79.9	67.5	73.7	61.2	7.68	4.96	6.32	3.79
0.02	0.70	80.1	67.5	73.8	61.2	7.41	4.53	5.97	3.61
0.03	0.87	80.2	67.5	73.9	61.3	7.20	4.15	5.68	3.44
0.04	1.04	80.4	67.6	74.0	61.3	7.06	3.82	5.44	3.29
0.05	1.20	80.5	67.6	74.1	61.4	6.97	3.52	5.25	3.13
0.06	1.37	80.7	67.6	74.1	61.4	6.94	3.26	5.10	2.99
0.07	1.54	80.8	67.6	74.2	61.5	6.95	3.02	4.99	2.85
0.08	1.70	80.9	67.7	74.3	61.5	7.01	2.80	4.91	2.72
0.09	1.87	81.0	67.7	74.4	61.6	7.12	2.60	4.86	2.59
0.10	2.04	81.2	67.7	74.4	61.6	7.25	2.42	4.84	2.47
0.11	2.20	81.3	67.7	74.5	61.7	7.43	2.26	4.84	2.36
0.12	2.37	81.4	67.7	74.5	61.7	7.63	2.10	4.87	2.25
0.13	2.54	81.4	67.7	74.6	61.8	7.86	1.96	4.91	2.14
0.14	2.70	81.5	67.8	74.6	61.8	8.12	1.83	4.98	2.05
0.15	2.87	81.6	67.8	74.7	61.9	8.40	1.73	5.06	1.96
0.16	3.04	81.7	67.8	74.7	61.9	8.70	1.63	5.16	1.87
0.17	3.20	81.8	67.8	74.8	62.0	9.01	1.55	5.28	1.79
0.18	3.37	81.8	67.8	74.8	62.0	9.33	1.48	5.41	1.71
0.19	3.54	81.9	67.8	74.9	62.1	9.67	1.42	5.54	1.64
0.20	3.71	82.0	67.8	74.9	62.1	10.01	1.37	5.69	1.57
0.21	3.87	82.0	67.8	74.9	62.2	10.35	1.32	5.84	1.51
0.22	4.04	82.1	67.8	75.0	62.2	10.69	1.28	5.99	1.45
0.23	4.21	82.1	67.9	75.0	62.3	11.03	1.25	6.14	1.39
0.24	4.38	82.2	67.9	75.0	62.3	11.36	1.22	6.29	1.34
0.25	4.54	82.2	67.9	75.0	62.4	11.69	1.20	6.44	1.29

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	4.71	82.3	67.9	75.1	62.4	12.00	1.18	6.59	1.24
0.27	4.88	82.3	67.9	75.1	62.5	12.30	1.16	6.73	1.19
0.28	5.05	82.3	67.9	75.1	62.5	12.58	1.15	6.86	1.15
0.29	5.21	82.4	67.9	75.1	62.6	12.84	1.14	6.99	1.11
0.30	5.38	82.4	67.9	75.2	62.6	13.08	1.13	7.11	1.07
0.31	5.55	82.4	67.9	75.2	62.7	13.30	1.13	7.22	1.03
0.32	5.72	82.5	67.9	75.2	62.7	13.49	1.13	7.31	0.99
0.33	5.88	82.5	67.9	75.2	62.8	13.66	1.13	7.40	0.96
0.34	6.05	82.5	67.9	75.2	62.8	13.80	1.14	7.47	0.92
0.35	6.22	82.6	67.9	75.2	62.9	13.92	1.15	7.54	0.89
0.36	6.39	82.6	67.9	75.3	62.9	14.01	1.17	7.59	0.86
0.37	6.56	82.6	67.9	75.3	63.0	14.06	1.18	7.62	0.85
0.38	6.73	82.6	67.9	75.3	63.0	14.09	1.20	7.65	0.83
0.39	6.89	82.7	67.9	75.3	63.1	14.09	1.22	7.66	0.81
0.40	7.06	82.7	67.9	75.3	63.1	14.07	1.25	7.66	0.80
0.41	7.23	82.7	67.9	75.3	63.2	14.02	1.28	7.65	0.78
0.42	7.40	82.7	68.0	75.3	63.2	13.94	1.31	7.63	0.77
0.43	7.57	82.7	68.0	75.3	63.3	13.84	1.35	7.59	0.75
0.44	7.74	82.7	68.0	75.3	63.3	13.71	1.39	7.55	0.74
0.45	7.90	82.8	68.0	75.4	63.4	13.57	1.44	7.50	0.72
0.46	8.07	82.8	68.0	75.4	63.4	13.40	1.49	7.45	0.71
0.47	8.24	82.8	68.0	75.4	63.5	13.22	1.55	7.39	0.69
0.48	8.41	82.8	68.0	75.4	63.5	13.03	1.61	7.32	0.68
0.49	8.58	82.8	68.0	75.4	63.6	12.82	1.68	7.25	0.66
0.50	8.75	82.8	68.0	75.4	63.6	12.61	1.75	7.18	0.65
0.51	8.92	82.8	68.0	75.4	63.7	12.39	1.83	7.11	0.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	9.09	82.8	68.0	75.4	63.7	12.16	1.91	7.04	0.62
0.53	9.25	82.8	68.0	75.4	63.8	11.93	2.00	6.97	0.60
0.54	9.42	82.9	68.0	75.4	63.8	11.71	2.09	6.90	0.59
0.55	9.59	82.9	68.0	75.4	63.9	11.49	2.19	6.84	0.58
0.56	9.76	82.9	68.0	75.4	63.9	11.28	2.30	6.79	0.56
0.57	9.93	82.9	68.0	75.4	64.0	11.07	2.41	6.74	0.55
0.58	10.10	82.9	68.0	75.4	64.0	10.88	2.51	6.70	0.54
0.59	10.27	82.9	68.0	75.4	64.1	10.70	2.62	6.66	0.53
0.60	10.44	82.9	68.0	75.4	64.1	10.54	2.72	6.63	0.52
0.61	10.61	82.9	68.0	75.4	64.2	10.40	2.82	6.61	0.50
0.62	10.78	82.9	68.0	75.4	64.3	10.28	2.91	6.59	0.49
0.63	10.95	82.9	68.0	75.4	64.3	10.17	2.99	6.58	0.48
0.64	11.12	82.9	68.0	75.5	64.4	10.08	3.06	6.57	0.47
0.65	11.29	82.9	68.0	75.5	64.4	10.00	3.13	6.56	0.46
0.66	11.45	82.9	68.0	75.5	64.5	9.93	3.19	6.56	0.46
0.67	11.62	82.9	68.0	75.5	64.5	9.87	3.24	6.56	0.45
0.68	11.79	82.9	68.0	75.5	64.6	9.82	3.30	6.56	0.44
0.69	11.96	82.9	68.0	75.5	64.6	9.78	3.34	6.56	0.43
0.70	12.13	82.9	68.0	75.5	64.7	9.74	3.39	6.56	0.42
0.71	12.30	82.9	68.0	75.5	64.7	9.71	3.43	6.57	0.41
0.72	12.47	82.9	68.0	75.5	64.8	9.68	3.46	6.57	0.41
0.73	12.64	83.0	68.0	75.5	64.8	9.65	3.50	6.58	0.40
0.74	12.81	83.0	68.0	75.5	64.9	9.63	3.53	6.58	0.40
0.75	12.98	83.0	68.0	75.5	64.9	9.62	3.56	6.59	0.40
0.76	13.15	83.0	68.0	75.5	65.0	9.60	3.59	6.60	0.40
0.77	13.32	83.0	68.0	75.5	65.0	9.59	3.62	6.60	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : SEPT.

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	13.49	83.0	68.0	75.5	65.1	9.58	3.64	6.61	0.40
0.79	13.66	83.0	68.0	75.5	65.1	9.57	3.66	6.62	0.40
0.80	13.83	83.0	68.0	75.5	65.2	9.56	3.68	6.62	0.40
0.81	14.00	83.0	68.0	75.5	65.2	9.56	3.70	6.63	0.40
0.82	14.17	83.0	68.0	75.5	65.3	9.55	3.72	6.64	0.40
0.83	14.35	83.0	68.0	75.5	65.3	9.55	3.74	6.64	0.40
0.84	14.52	83.0	68.0	75.5	65.4	9.54	3.76	6.65	0.40
0.85	14.69	83.0	68.0	75.5	65.4	9.54	3.77	6.65	0.40
0.86	14.86	83.0	68.0	75.5	65.5	9.54	3.78	6.66	0.40
0.87	15.03	83.0	68.0	75.5	65.5	9.53	3.80	6.67	0.40
0.88	15.20	83.0	68.0	75.5	65.6	9.53	3.81	6.67	0.40
0.89	15.37	83.0	68.0	75.5	65.6	9.53	3.82	6.68	0.40
0.90	15.54	83.0	68.0	75.5	65.7	9.53	3.83	6.68	0.40
0.91	15.71	83.0	68.0	75.5	65.7	9.53	3.85	6.69	0.40
0.92	15.88	83.0	68.0	75.5	65.8	9.53	3.86	6.69	0.40
0.93	16.05	83.0	68.0	75.5	65.8	9.53	3.87	6.70	0.40
0.94	16.22	83.0	68.0	75.5	65.9	9.53	3.88	6.70	0.40
0.95	16.39	83.0	68.0	75.5	65.9	9.53	3.88	6.71	0.40
0.96	16.57	83.0	68.0	75.5	66.0	9.53	3.89	6.71	0.40
0.97	16.74	83.0	68.0	75.5	66.0	9.53	3.90	6.71	0.40
0.98	16.91	83.0	68.0	75.5	66.1	9.53	3.91	6.72	0.40
0.99	17.08	83.0	68.0	75.5	66.1	9.53	3.92	6.72	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.50	1.01	3.51	0.55	4.06	3.00	0.40	0.10
0.0	0.37	4.95	1.26	6.21	5.43	11.64	3.36	4.88	18.29
0.01	0.54	4.80	1.25	6.05	5.18	11.23	3.30	4.80	17.03
0.02	0.70	4.62	1.24	5.86	4.94	10.80	3.24	4.73	15.86
0.03	0.87	4.45	1.23	5.68	4.71	10.39	3.17	4.65	14.77
0.04	1.04	4.29	1.22	5.51	4.49	10.00	3.10	4.58	13.76
0.05	1.20	4.13	1.21	5.34	4.29	9.63	3.06	4.50	12.81
0.06	1.37	3.99	1.20	5.19	4.09	9.27	3.04	4.43	11.93
0.07	1.54	3.85	1.19	5.03	3.90	8.93	3.01	4.36	11.11
0.08	1.70	3.71	1.18	4.89	3.72	8.61	3.00	4.29	10.34
0.09	1.87	3.58	1.17	4.75	3.55	8.30	3.00	4.22	9.63
0.10	2.04	3.46	1.17	4.62	3.38	8.01	3.00	4.15	8.97
0.11	2.20	3.34	1.16	4.50	3.22	7.72	3.00	4.08	8.35
0.12	2.37	3.22	1.16	4.38	3.08	7.46	3.00	4.01	7.78
0.13	2.54	3.11	1.15	4.27	2.93	7.20	3.00	3.95	7.25
0.14	2.70	3.01	1.15	4.16	2.80	6.96	3.00	3.88	6.75
0.15	2.87	2.91	1.15	4.05	2.67	6.73	3.00	3.82	6.29
0.16	3.04	2.81	1.14	3.95	2.56	6.51	3.00	3.76	5.86
0.17	3.20	2.72	1.14	3.86	2.45	6.31	3.00	3.70	5.46
0.18	3.37	2.63	1.14	3.77	2.34	6.11	3.00	3.64	5.08
0.19	3.54	2.54	1.14	3.68	2.25	5.93	3.00	3.58	4.74
0.20	3.71	2.46	1.14	3.60	2.15	5.75	3.00	3.52	4.42
0.21	3.87	2.38	1.14	3.52	2.07	5.59	3.00	3.46	4.12
0.22	4.04	2.31	1.14	3.44	1.98	5.43	3.00	3.40	3.84
0.23	4.21	2.23	1.14	3.37	1.91	5.28	3.00	3.35	3.58
0.24	4.38	2.16	1.14	3.30	1.83	5.13	3.00	3.29	3.33
0.25	4.54	2.09	1.14	3.24	1.76	5.00	3.00	3.24	3.11

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	4.71	2.03	1.14	3.17	1.69	4.87	3.00	3.18	2.90
0.27	4.88	1.97	1.15	3.11	1.63	4.74	3.00	3.13	2.71
0.28	5.05	1.90	1.15	3.05	1.57	4.62	3.00	3.08	2.52
0.29	5.21	1.85	1.15	3.00	1.51	4.51	3.00	3.03	2.36
0.30	5.38	1.79	1.16	2.95	1.46	4.40	3.00	2.98	2.20
0.31	5.55	1.74	1.16	2.90	1.41	4.30	3.00	2.93	2.05
0.32	5.72	1.68	1.16	2.85	1.36	4.20	3.00	2.88	1.92
0.33	5.88	1.63	1.17	2.80	1.31	4.11	3.00	2.83	1.79
0.34	6.05	1.58	1.17	2.76	1.26	4.02	3.00	2.79	1.67
0.35	6.22	1.54	1.18	2.71	1.22	3.93	3.00	2.74	1.56
0.36	6.39	1.49	1.18	2.67	1.18	3.85	3.00	2.70	1.46
0.37	6.56	1.45	1.19	2.63	1.14	3.77	3.00	2.65	1.36
0.38	6.73	1.41	1.19	2.60	1.10	3.69	3.00	2.61	1.27
0.39	6.89	1.36	1.20	2.56	1.06	3.62	3.00	2.57	1.19
0.40	7.06	1.33	1.20	2.53	1.02	3.55	3.00	2.53	1.11
0.41	7.23	1.29	1.21	2.50	0.99	3.49	3.00	2.49	1.04
0.42	7.40	1.25	1.22	2.47	0.96	3.42	3.00	2.44	0.97
0.43	7.57	1.21	1.22	2.44	0.92	3.36	3.00	2.41	0.91
0.44	7.74	1.18	1.23	2.41	0.89	3.30	3.00	2.37	0.85
0.45	7.90	1.15	1.23	2.38	0.86	3.24	3.00	2.33	0.80
0.46	8.07	1.11	1.24	2.36	0.83	3.19	3.00	2.29	0.74
0.47	8.24	1.08	1.25	2.33	0.80	3.13	3.00	2.25	0.70
0.48	8.41	1.05	1.26	2.31	0.77	3.08	3.00	2.22	0.65
0.49	8.58	1.02	1.26	2.29	0.75	3.03	3.00	2.18	0.61
0.50	8.75	0.99	1.27	2.27	0.72	2.98	3.00	2.15	0.57
0.51	8.92	0.97	1.28	2.25	0.69	2.94	3.00	2.11	0.53

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	9.09	0.94	1.29	2.23	0.67	2.89	3.00	2.08	0.50
0.53	9.25	0.91	1.29	2.21	0.64	2.85	3.00	2.05	0.47
0.54	9.42	0.89	1.30	2.19	0.62	2.81	3.00	2.01	0.44
0.55	9.59	0.87	1.31	2.17	0.59	2.77	3.00	1.98	0.41
0.56	9.76	0.84	1.32	2.16	0.57	2.73	3.00	1.95	0.39
0.57	9.93	0.82	1.33	2.14	0.55	2.69	3.00	1.92	0.36
0.58	10.10	0.80	1.33	2.13	0.53	2.66	3.00	1.89	0.34
0.59	10.27	0.78	1.34	2.12	0.51	2.62	3.00	1.86	0.32
0.60	10.44	0.75	1.35	2.11	0.49	2.59	3.00	1.83	0.30
0.61	10.61	0.73	1.36	2.09	0.47	2.56	3.00	1.80	0.29
0.62	10.78	0.71	1.37	2.08	0.45	2.53	3.00	1.77	0.27
0.63	10.95	0.70	1.38	2.07	0.43	2.51	3.00	1.74	0.26
0.64	11.12	0.68	1.39	2.06	0.42	2.48	3.00	1.72	0.25
0.65	11.29	0.66	1.39	2.05	0.40	2.46	3.00	1.69	0.24
0.66	11.45	0.64	1.40	2.05	0.39	2.43	3.00	1.66	0.23
0.67	11.62	0.62	1.41	2.04	0.37	2.41	3.00	1.64	0.22
0.68	11.79	0.61	1.42	2.03	0.36	2.39	3.00	1.61	0.21
0.69	11.96	0.59	1.43	2.02	0.35	2.37	3.00	1.59	0.20
0.70	12.13	0.58	1.44	2.02	0.33	2.35	3.00	1.56	0.19
0.71	12.30	0.56	1.45	2.01	0.32	2.33	3.00	1.54	0.18
0.72	12.47	0.55	1.46	2.00	0.31	2.31	3.00	1.51	0.17
0.73	12.64	0.53	1.47	2.00	0.30	2.30	3.00	1.49	0.17
0.74	12.81	0.52	1.48	2.00	0.29	2.28	3.00	1.47	0.16
0.75	12.98	0.51	1.49	1.99	0.28	2.27	3.00	1.44	0.15
0.76	13.15	0.49	1.49	1.99	0.27	2.25	3.00	1.42	0.15
0.77	13.32	0.48	1.50	1.98	0.26	2.24	3.00	1.40	0.14

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

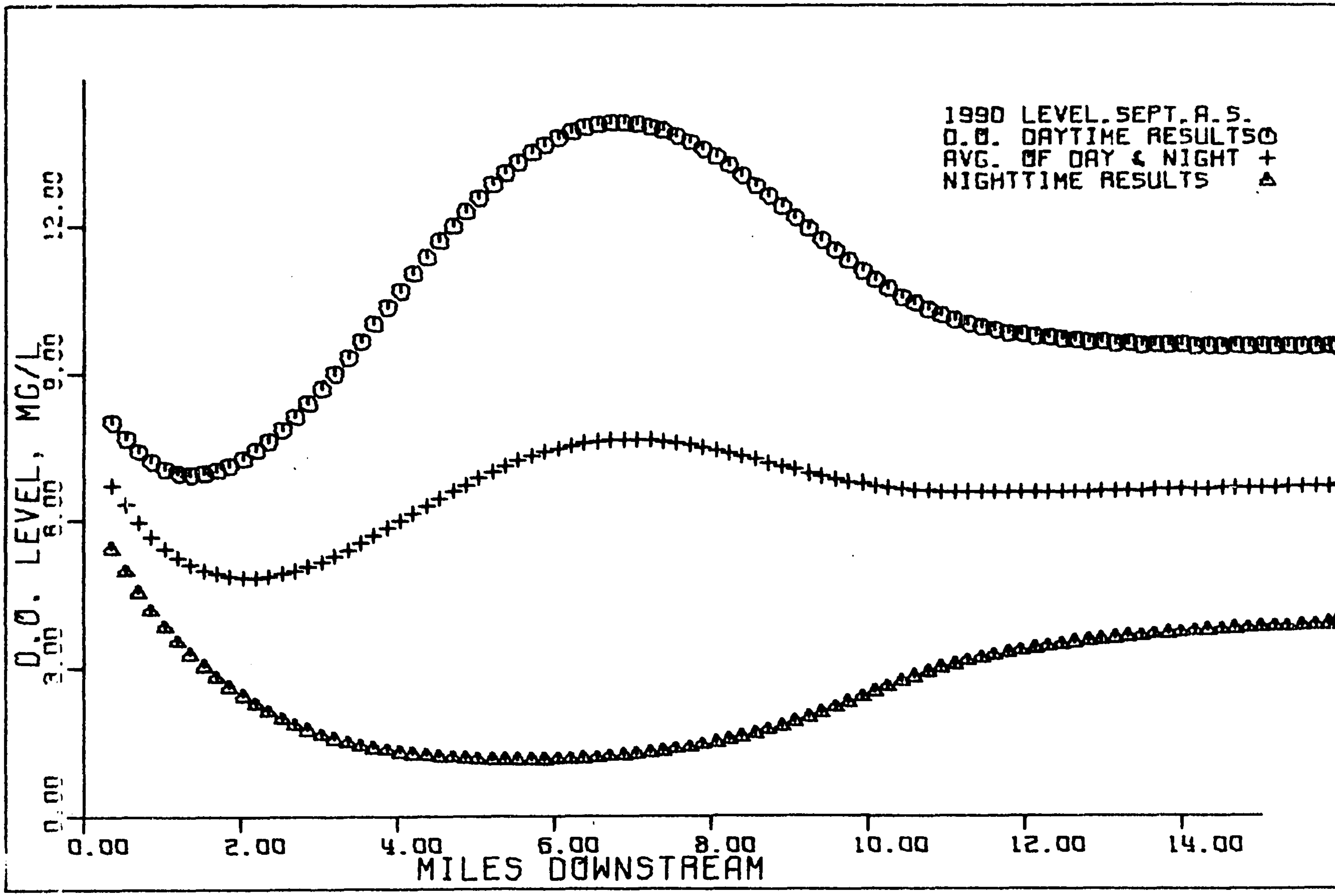
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	13.49	0.47	1.51	1.98	0.25	2.23	3.00	1.38	0.14
0.79	13.66	0.46	1.52	1.98	0.24	2.22	3.00	1.36	0.13
0.80	13.83	0.44	1.53	1.98	0.23	2.21	3.00	1.34	0.13
0.81	14.00	0.43	1.54	1.97	0.22	2.20	3.00	1.32	0.12
0.82	14.17	0.42	1.55	1.97	0.21	2.19	3.00	1.30	0.12
0.83	14.35	0.41	1.56	1.97	0.21	2.18	3.00	1.28	0.11
0.84	14.52	0.40	1.57	1.97	0.20	2.17	3.00	1.26	0.11
0.85	14.69	0.39	1.58	1.97	0.19	2.16	3.00	1.24	0.11
0.86	14.86	0.38	1.59	1.97	0.19	2.15	3.00	1.22	0.10
0.87	15.03	0.37	1.60	1.97	0.18	2.15	3.00	1.20	0.10
0.88	15.20	0.36	1.61	1.97	0.17	2.14	3.00	1.18	0.10
0.89	15.37	0.35	1.62	1.97	0.17	2.13	3.00	1.17	0.10
0.90	15.54	0.34	1.63	1.97	0.16	2.13	3.00	1.15	0.10
0.91	15.71	0.33	1.64	1.97	0.16	2.12	3.00	1.13	0.10
0.92	15.88	0.33	1.64	1.97	0.15	2.12	3.00	1.11	0.10
0.93	16.05	0.32	1.65	1.97	0.15	2.12	3.00	1.10	0.10
0.94	16.22	0.31	1.66	1.97	0.14	2.11	3.00	1.08	0.10
0.95	16.39	0.30	1.67	1.97	0.14	2.11	3.00	1.06	0.10
0.96	16.57	0.29	1.68	1.98	0.13	2.11	3.00	1.05	0.10
0.97	16.74	0.29	1.69	1.98	0.13	2.10	3.00	1.03	0.10
0.98	16.91	0.28	1.70	1.98	0.12	2.10	3.00	1.02	0.10
0.99	17.08	0.27	1.71	1.98	0.12	2.10	3.00	1.00	0.10

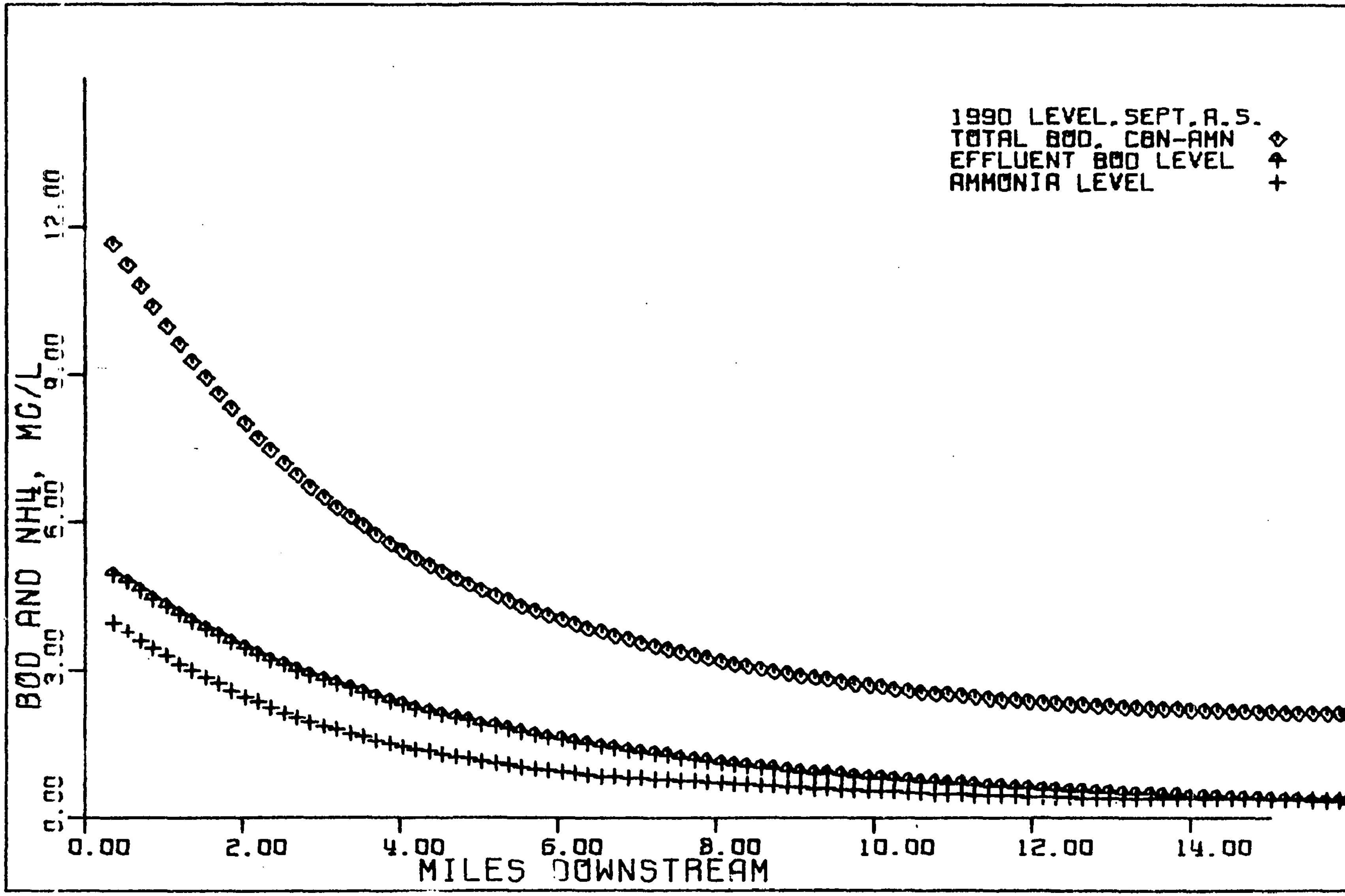
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : SEPT.
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	8.02	0.37	0.0	5.42	0.37	0.0
MINIMUM DO, MG/L	6.94	1.37	0.06	1.13	5.55	0.31
FINAL DO, MG/L	9.56	13.83	0.80	3.68	13.83	0.80
DO DEFICIT						
INITIAL, MG/L	-0.32	0.37	0.0	3.38	0.37	0.0
FINAL, MG/L	-2.11	13.83	0.80	5.07	13.83	0.80
RIVER DISCHARGE						
INITIAL, CFS	61.13	0.37	0.0	61.13	0.37	0.0
FINAL, CFS	65.17	13.83	0.80	65.17	13.83	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	79.72	0.37	0.0	67.45	0.37	0.0
FINAL, DEG F	82.97	13.83	0.80	67.99	13.83	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	4.95	0.37	0.0	4.95	0.37	0.0
FINAL BOD, MG/L	0.30	13.83	0.80	0.58	13.83	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.03	0.37	0.0	0.03	0.37	0.0
FINAL BOD IN RIVER	1.36	13.83	0.80	1.71	13.83	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	5.43	0.37	0.0	5.43	0.37	0.0
FINAL BOD, MG/L	0.03	13.83	0.80	0.43	13.83	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	11.39	0.37	0.0	11.89	0.37	0.0
FINAL VALUE, MG/L	1.69	13.83	0.80	2.72	13.83	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	3.97	0.37	0.0	3.97	0.37	0.0
FINAL VALUE, MG/L	0.40	13.83	0.80	0.40	13.83	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.36	0.37	0.0	3.36	0.37	0.0
FINAL VALUE, MG/L	3.00	13.83	0.80	3.00	13.83	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.88	0.37	0.0	4.88	0.37	0.0
FINAL VALUE, MG/L	0.84	13.83	0.80	1.84	13.83	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	18.29	0.37	0.0	18.29	0.37	0.0
FINAL PERCENT	0.10	13.83	0.80	0.15	13.83	0.80


1990 LEVEL.SEPT.A.S.
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
MILES DOWNSTREAM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00


1990 LEVEL.SEPT.A.S.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
MILES DOWNSTREAM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00

H. Computer Results for 1990 Design Level, Activated Sludge and Ames Reservoir, October-November, 10 Yr

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
7.19	60.00	25.00	0.0	12.00	0.080	0.0	20.00	5.00	25.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
73.00	58.00	130.00	65.00	3.00	0.140	0.0	0.40	3.00	0.40	0.10	70.00	3.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.15	115.00	50.00	0.149	0.374	0.37	0.0	1.00	0.01	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
73.00	58.00	2.500	0.0	0.0	3.000	0.100	0.40	1.00	1.50	2.50	1.00	4.00	0.0	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	0	0	0	0	26

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 70.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 3.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 11.13 CFS, RIVER Q = 50.00 CFS, TOTAL Q = 61.13 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 1.00 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	73.0	58.0		50.0	10.76	6.41		0.40
0.0	0.37	70.6	58.4	64.5	61.1	9.24	5.68	7.46	3.97
0.01	0.54	70.8	58.3	64.6	61.2	8.98	5.34	7.16	3.85
0.02	0.70	70.9	58.3	64.6	61.2	8.76	5.02	6.89	3.73
0.03	0.87	71.0	58.3	64.7	61.2	8.59	4.74	6.67	3.61
0.04	1.04	71.1	58.3	64.7	61.2	8.44	4.49	6.47	3.50
0.05	1.20	71.2	58.3	64.7	61.3	8.33	4.27	6.30	3.39
0.06	1.37	71.3	58.3	64.8	61.3	8.25	4.08	6.16	3.28
0.07	1.53	71.4	58.2	64.8	61.3	8.20	3.90	6.05	3.18
0.08	1.70	71.5	58.2	64.9	61.3	8.18	3.74	5.96	3.08
0.09	1.87	71.6	58.2	64.9	61.4	8.18	3.60	5.89	2.99
0.10	2.03	71.7	58.2	64.9	61.4	8.20	3.48	5.84	2.89
0.11	2.20	71.7	58.2	65.0	61.4	8.24	3.36	5.80	2.80
0.12	2.37	71.8	58.2	65.0	61.4	8.30	3.26	5.78	2.72
0.13	2.53	71.9	58.2	65.0	61.5	8.38	3.18	5.78	2.63
0.14	2.70	71.9	58.2	65.1	61.5	8.48	3.10	5.79	2.55
0.15	2.87	72.0	58.2	65.1	61.5	8.59	3.02	5.81	2.47
0.16	3.03	72.1	58.1	65.1	61.5	8.72	2.96	5.84	2.39
0.17	3.20	72.1	58.1	65.1	61.6	8.86	2.91	5.88	2.32
0.18	3.37	72.2	58.1	65.1	61.6	9.01	2.86	5.93	2.25
0.19	3.53	72.2	58.1	65.2	61.6	9.17	2.81	5.99	2.18
0.20	3.70	72.3	58.1	65.2	61.6	9.35	2.77	6.06	2.11
0.21	3.87	72.3	58.1	65.2	61.7	9.53	2.74	6.13	2.05
0.22	4.03	72.3	58.1	65.2	61.7	9.71	2.71	6.21	1.99
0.23	4.20	72.4	58.1	65.2	61.7	9.91	2.69	6.30	1.92
0.24	4.37	72.4	58.1	65.2	61.7	10.11	2.67	6.39	1.87
0.25	4.54	72.4	58.1	65.3	61.8	10.32	2.65	6.48	1.81

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.26	4.70	72.5	58.1	65.3	61.8	10.52	2.64	6.58	1.75
0.27	4.87	72.5	58.1	65.3	61.8	10.73	2.62	6.68	1.70
C.28	5.04	72.5	58.1	65.3	61.8	10.95	2.62	6.78	1.65
0.29	5.20	72.6	58.1	65.3	61.9	11.16	2.61	6.89	1.60
0.30	5.37	72.6	58.1	65.3	61.9	11.37	2.61	6.99	1.55
0.31	5.54	72.6	58.1	65.3	61.9	11.59	2.61	7.10	1.51
0.32	5.70	72.6	58.1	65.3	61.9	11.80	2.61	7.20	1.46
0.33	5.87	72.6	58.1	65.3	62.0	12.00	2.61	7.31	1.42
0.34	6.04	72.7	58.1	65.4	62.0	12.21	2.61	7.41	1.38
0.35	6.21	72.7	58.0	65.4	62.0	12.41	2.62	7.51	1.33
0.36	6.37	72.7	58.0	65.4	62.0	12.60	2.62	7.61	1.30
0.37	6.54	72.7	58.0	65.4	62.1	12.79	2.63	7.71	1.26
0.38	6.71	72.7	58.0	65.4	62.1	12.97	2.64	7.80	1.22
0.39	6.87	72.7	58.0	65.4	62.1	13.14	2.65	7.90	1.18
0.40	7.04	72.8	58.0	65.4	62.1	13.31	2.66	7.98	1.15
0.41	7.21	72.8	58.0	65.4	62.2	13.46	2.68	8.07	1.12
0.42	7.38	72.8	58.0	65.4	62.2	13.61	2.69	8.15	1.08
0.43	7.54	72.8	58.0	65.4	62.2	13.74	2.70	8.22	1.05
0.44	7.71	72.8	58.0	65.4	62.2	13.87	2.72	8.29	1.02
0.45	7.88	72.8	58.0	65.4	62.3	13.98	2.73	8.36	0.99
0.46	8.05	72.8	58.0	65.4	62.3	14.09	2.75	8.42	0.96
0.47	8.21	72.8	58.0	65.4	62.3	14.18	2.76	8.47	0.94
0.48	8.38	72.9	58.0	65.4	62.3	14.26	2.78	8.52	0.91
0.49	8.55	72.9	58.0	65.4	62.4	14.33	2.80	8.56	0.88
0.50	8.72	72.9	58.0	65.4	62.4	14.38	2.81	8.60	0.86
0.51	8.88	72.9	58.0	65.4	62.4	14.43	2.83	8.63	0.84

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	9.05	72.9	58.0	65.4	62.4	14.46	2.85	8.65	0.81
0.53	9.22	72.9	58.0	65.5	62.5	14.48	2.87	8.67	0.79
0.54	9.39	72.9	58.0	65.5	62.5	14.48	2.89	8.69	0.77
0.55	9.55	72.9	58.0	65.5	62.5	14.48	2.91	8.69	0.75
0.56	9.72	72.9	58.0	65.5	62.5	14.46	2.93	8.69	0.74
0.57	9.89	72.9	58.0	65.5	62.6	14.43	2.95	8.69	0.73
0.58	10.06	72.9	58.0	65.5	62.6	14.39	2.97	8.68	0.72
0.59	10.23	72.9	58.0	65.5	62.6	14.33	2.99	8.66	0.71
0.60	10.39	72.9	58.0	65.5	62.6	14.27	3.01	8.64	0.69
0.61	10.56	72.9	58.0	65.5	62.7	14.20	3.04	8.62	0.68
0.62	10.73	72.9	58.0	65.5	62.7	14.11	3.06	8.59	0.67
0.63	10.90	72.9	58.0	65.5	62.7	14.02	3.08	8.55	0.66
0.64	11.06	72.9	58.0	65.5	62.7	13.92	3.11	8.51	0.65
0.65	11.23	72.9	58.0	65.5	62.8	13.81	3.13	8.47	0.64
0.66	11.40	72.9	58.0	65.5	62.8	13.69	3.16	8.42	0.63
0.67	11.57	72.9	58.0	65.5	62.8	13.57	3.18	8.37	0.62
0.68	11.74	73.0	58.0	65.5	62.8	13.44	3.21	8.32	0.61
0.69	11.90	73.0	58.0	65.5	62.9	13.30	3.24	8.27	0.60
0.70	12.07	73.0	58.0	65.5	62.9	13.16	3.26	8.21	0.59
0.71	12.24	73.0	58.0	65.5	62.9	13.02	3.29	8.16	0.58
0.72	12.41	73.0	58.0	65.5	62.9	12.87	3.32	8.10	0.57
0.73	12.58	73.0	58.0	65.5	63.0	12.72	3.36	8.04	0.57
0.74	12.75	73.0	58.0	65.5	63.0	12.58	3.39	7.98	0.56
0.75	12.91	73.0	58.0	65.5	63.0	12.43	3.42	7.92	0.55
0.76	13.08	73.0	58.0	65.5	63.0	12.28	3.46	7.87	0.54
0.77	13.25	73.0	58.0	65.5	63.1	12.13	3.49	7.81	0.53

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.78	13.42	73.0	58.0	65.5	63.1	11.98	3.53	7.76	0.53
0.79	13.59	73.0	58.0	65.5	63.1	11.84	3.56	7.70	0.52
0.80	13.75	73.0	58.0	65.5	63.1	11.70	3.60	7.65	0.51
0.81	13.92	73.0	58.0	65.5	63.2	11.57	3.64	7.60	0.51
0.82	14.09	73.0	58.0	65.5	63.2	11.44	3.68	7.56	0.50
0.83	14.26	73.0	58.0	65.5	63.2	11.32	3.72	7.52	0.49
0.84	14.43	73.0	58.0	65.5	63.2	11.20	3.76	7.48	0.48
0.85	14.60	73.0	58.0	65.5	63.3	11.09	3.79	7.44	0.48
0.86	14.77	73.0	58.0	65.5	63.3	10.99	3.83	7.41	0.47
0.87	14.93	73.0	58.0	65.5	63.3	10.89	3.87	7.38	0.47
0.88	15.10	73.0	58.0	65.5	63.3	10.81	3.90	7.36	0.46
0.89	15.27	73.0	58.0	65.5	63.4	10.74	3.93	7.33	0.45
0.90	15.44	73.0	58.0	65.5	63.4	10.67	3.96	7.32	0.45
0.91	15.61	73.0	58.0	65.5	63.4	10.61	3.99	7.30	0.44
0.92	15.78	73.0	58.0	65.5	63.4	10.56	4.01	7.29	0.44
0.93	15.94	73.0	58.0	65.5	63.5	10.52	4.04	7.28	0.43
0.94	16.11	73.0	58.0	65.5	63.5	10.48	4.06	7.27	0.43
0.95	16.28	73.0	58.0	65.5	63.5	10.44	4.08	7.26	0.42
0.96	16.45	73.0	58.0	65.5	63.5	10.41	4.10	7.25	0.42
0.97	16.62	73.0	58.0	65.5	63.6	10.38	4.11	7.25	0.41
0.98	16.79	73.0	58.0	65.5	63.6	10.36	4.13	7.25	0.41
0.99	16.96	73.0	58.0	65.5	63.6	10.34	4.14	7.24	0.40

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	3.00	1.16	4.16	0.55	4.71	3.00	0.40	0.10
0.0	0.37	5.36	1.40	6.76	5.43	12.19	3.36	4.88	18.29
0.01	0.54	5.22	1.40	6.63	5.26	11.89	3.32	4.83	17.31
0.02	0.70	5.07	1.40	6.47	5.10	11.57	3.28	4.78	16.39
0.03	0.87	4.92	1.40	6.32	4.94	11.26	3.23	4.72	15.51
0.04	1.04	4.78	1.39	6.17	4.78	10.96	3.19	4.67	14.68
0.05	1.20	4.64	1.39	6.03	4.63	10.67	3.14	4.62	13.90
0.06	1.37	4.51	1.39	5.90	4.49	10.39	3.10	4.57	13.16
0.07	1.53	4.38	1.39	5.77	4.35	10.12	3.07	4.53	12.45
0.08	1.70	4.26	1.39	5.64	4.21	9.86	3.05	4.48	11.79
0.09	1.87	4.14	1.38	5.52	4.08	9.61	3.04	4.43	11.16
0.10	2.03	4.02	1.38	5.41	3.96	9.36	3.02	4.38	10.57
0.11	2.20	3.91	1.38	5.29	3.83	9.13	3.00	4.33	10.00
0.12	2.37	3.80	1.39	5.19	3.71	8.90	3.00	4.29	9.47
0.13	2.53	3.70	1.39	5.08	3.60	8.68	3.00	4.24	8.97
0.14	2.70	3.60	1.39	4.98	3.49	8.47	3.00	4.19	8.49
0.15	2.87	3.50	1.39	4.89	3.38	8.27	3.00	4.15	8.04
0.16	3.03	3.40	1.39	4.79	3.27	8.07	3.00	4.10	7.62
0.17	3.20	3.31	1.39	4.70	3.17	7.88	3.00	4.06	7.21
0.18	3.37	3.22	1.40	4.62	3.08	7.69	3.00	4.02	6.83
0.19	3.53	3.14	1.40	4.54	2.98	7.52	3.00	3.97	6.47
0.20	3.70	3.05	1.40	4.46	2.89	7.35	3.00	3.93	6.13
0.21	3.87	2.97	1.41	4.38	2.80	7.18	3.00	3.89	5.81
0.22	4.03	2.89	1.41	4.31	2.72	7.02	3.00	3.84	5.50
0.23	4.20	2.82	1.42	4.23	2.63	6.87	3.00	3.80	5.22
0.24	4.37	2.75	1.42	4.17	2.55	6.72	3.00	3.76	4.94
0.25	4.54	2.67	1.43	4.10	2.48	6.58	3.00	3.72	4.68

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.26	4.70	2.61	1.43	4.04	2.40	6.44	3.00	3.68	4.44
0.27	4.87	2.54	1.44	3.98	2.33	6.30	3.00	3.64	4.21
0.28	5.04	2.47	1.44	3.92	2.26	6.17	3.00	3.60	3.99
0.29	5.20	2.41	1.45	3.86	2.19	6.05	3.00	3.56	3.78
0.30	5.37	2.35	1.45	3.81	2.12	5.93	3.00	3.52	3.59
0.31	5.54	2.29	1.46	3.75	2.06	5.81	3.00	3.49	3.40
0.32	5.70	2.24	1.47	3.70	2.00	5.70	3.00	3.45	3.23
0.33	5.87	2.18	1.47	3.65	1.94	5.59	3.00	3.41	3.06
0.34	6.04	2.13	1.48	3.61	1.88	5.49	3.00	3.37	2.90
0.35	6.21	2.07	1.49	3.56	1.83	5.39	3.00	3.34	2.75
0.36	6.37	2.02	1.50	3.52	1.77	5.29	3.00	3.30	2.61
0.37	6.54	1.97	1.50	3.48	1.72	5.20	3.00	3.27	2.48
0.38	6.71	1.93	1.51	3.44	1.67	5.11	3.00	3.23	2.35
0.39	6.87	1.88	1.52	3.40	1.62	5.02	3.00	3.20	2.23
0.40	7.04	1.83	1.53	3.36	1.57	4.94	3.00	3.16	2.12
0.41	7.21	1.79	1.54	3.33	1.53	4.86	3.00	3.13	2.01
0.42	7.38	1.75	1.55	3.29	1.48	4.78	3.00	3.09	1.91
0.43	7.54	1.71	1.56	3.26	1.44	4.70	3.00	3.06	1.81
0.44	7.71	1.67	1.56	3.23	1.40	4.63	3.00	3.03	1.72
0.45	7.88	1.63	1.57	3.20	1.36	4.56	3.00	3.00	1.64
0.46	8.05	1.59	1.58	3.17	1.32	4.49	3.00	2.96	1.55
0.47	8.21	1.55	1.59	3.14	1.28	4.42	3.00	2.93	1.48
0.48	8.38	1.51	1.60	3.12	1.25	4.36	3.00	2.90	1.40
0.49	8.55	1.48	1.61	3.09	1.21	4.30	3.00	2.87	1.33
0.50	8.72	1.44	1.62	3.07	1.18	4.24	3.00	2.84	1.27
0.51	8.88	1.41	1.63	3.04	1.14	4.18	3.00	2.81	1.20

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	9.05	1.38	1.64	3.02	1.11	4.13	3.00	2.78	1.14
0.53	9.22	1.35	1.65	3.00	1.08	4.08	3.00	2.75	1.09
0.54	9.39	1.32	1.66	2.98	1.05	4.03	3.00	2.72	1.03
0.55	9.55	1.29	1.67	2.96	1.02	3.98	3.00	2.69	0.98
0.56	9.72	1.26	1.68	2.94	0.99	3.93	3.00	2.66	0.93
0.57	9.89	1.23	1.69	2.92	0.96	3.88	3.00	2.63	0.89
0.58	10.06	1.20	1.70	2.90	0.94	3.84	3.00	2.61	0.84
0.59	10.23	1.17	1.71	2.89	0.91	3.80	3.00	2.58	0.80
0.60	10.39	1.15	1.72	2.87	0.89	3.76	3.00	2.55	0.76
0.61	10.56	1.12	1.74	2.86	0.86	3.72	3.00	2.52	0.73
0.62	10.73	1.10	1.75	2.84	0.84	3.68	3.00	2.50	0.69
0.63	10.90	1.07	1.76	2.83	0.82	3.65	3.00	2.47	0.66
0.64	11.06	1.05	1.77	2.82	0.79	3.61	3.00	2.45	0.63
0.65	11.23	1.03	1.78	2.80	0.77	3.58	3.00	2.42	0.59
0.66	11.40	1.00	1.79	2.79	0.75	3.54	3.00	2.39	0.57
0.67	11.57	0.98	1.80	2.78	0.73	3.51	3.00	2.37	0.54
0.68	11.74	0.96	1.81	2.77	0.71	3.48	3.00	2.34	0.51
0.69	11.90	0.94	1.82	2.76	0.69	3.45	3.00	2.32	0.49
0.70	12.07	0.92	1.84	2.75	0.67	3.43	3.00	2.30	0.46
0.71	12.24	0.90	1.85	2.74	0.66	3.40	3.00	2.27	0.44
0.72	12.41	0.88	1.86	2.74	0.64	3.37	3.00	2.25	0.42
0.73	12.58	0.86	1.87	2.73	0.62	3.35	3.00	2.22	0.40
0.74	12.75	0.84	1.88	2.72	0.60	3.33	3.00	2.20	0.38
0.75	12.91	0.82	1.89	2.72	0.59	3.30	3.00	2.18	0.36
0.76	13.08	0.80	1.91	2.71	0.57	3.28	3.00	2.16	0.35
0.77	13.25	0.79	1.92	2.70	0.56	3.26	3.00	2.13	0.33

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

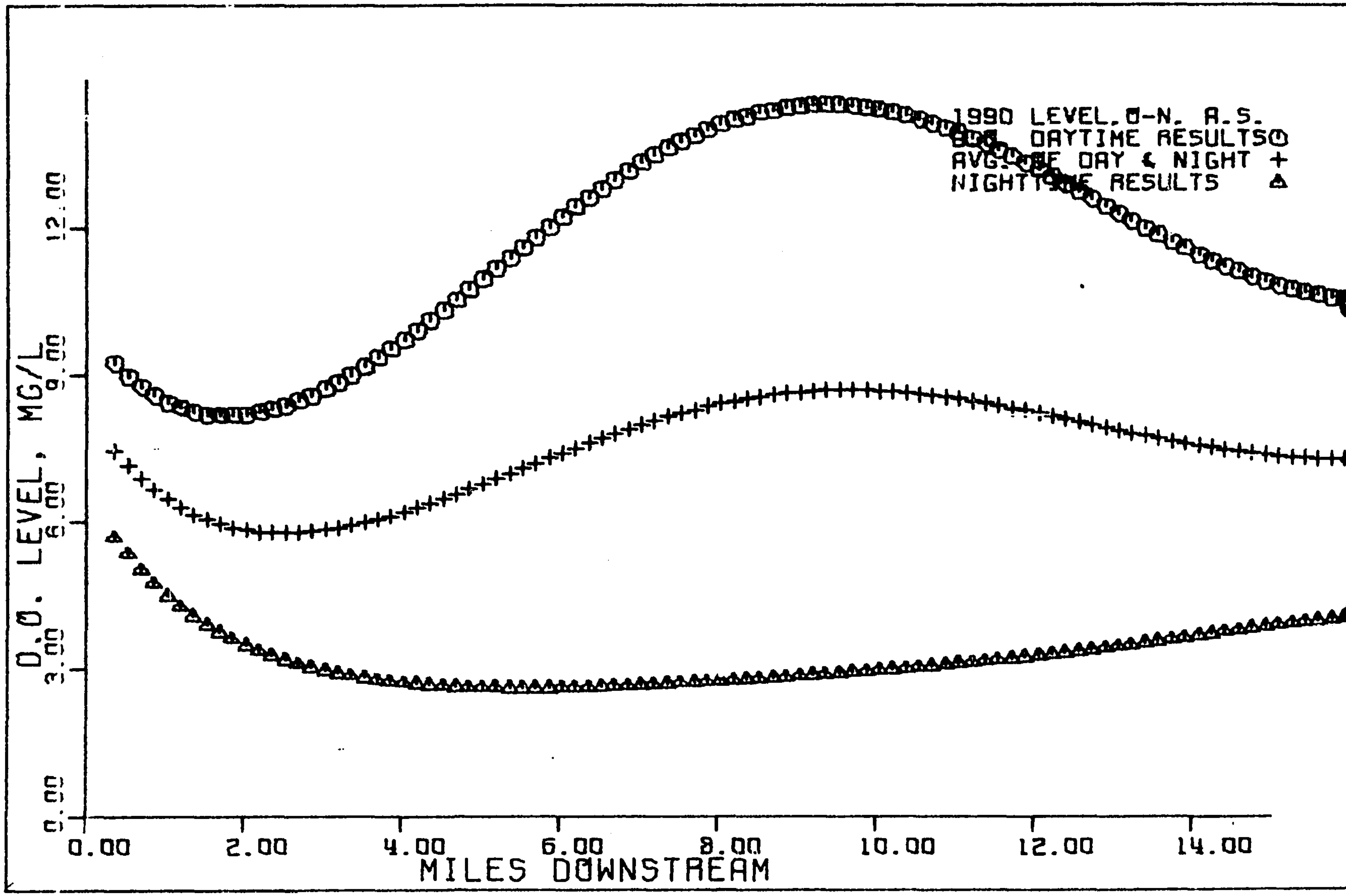
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.78	13.42	0.77	1.93	2.70	0.54	3.24	3.00	2.11	0.32
0.79	13.59	0.75	1.94	2.69	0.53	3.22	3.00	2.09	0.30
0.80	13.75	0.74	1.95	2.69	0.52	3.20	3.00	2.07	0.29
0.81	13.92	0.72	1.96	2.68	0.50	3.19	3.00	2.05	0.28
0.82	14.09	0.71	1.98	2.68	0.49	3.17	3.00	2.03	0.27
0.83	14.26	0.69	1.99	2.68	0.48	3.15	3.00	2.00	0.26
0.84	14.43	0.68	2.00	2.68	0.46	3.14	3.00	1.98	0.25
0.85	14.60	0.66	2.01	2.67	0.45	3.13	3.00	1.96	0.24
0.86	14.77	0.65	2.02	2.67	0.44	3.11	3.00	1.94	0.24
0.87	14.93	0.63	2.04	2.67	0.43	3.10	3.00	1.92	0.23
0.88	15.10	0.62	2.05	2.67	0.42	3.09	3.00	1.90	0.22
0.89	15.27	0.61	2.06	2.67	0.41	3.07	3.00	1.88	0.21
0.90	15.44	0.59	2.07	2.66	0.40	3.06	3.00	1.87	0.21
0.91	15.61	0.58	2.08	2.66	0.39	3.05	3.00	1.85	0.20
0.92	15.78	0.57	2.10	2.66	0.38	3.04	3.00	1.83	0.19
0.93	15.94	0.56	2.11	2.66	0.37	3.03	3.00	1.81	0.19
0.94	16.11	0.54	2.12	2.66	0.36	3.02	3.00	1.79	0.18
0.95	16.28	0.53	2.13	2.66	0.35	3.01	3.00	1.77	0.17
0.96	16.45	0.52	2.14	2.67	0.34	3.01	3.00	1.75	0.17
0.97	16.62	0.51	2.16	2.67	0.33	3.00	3.00	1.74	0.16
0.98	16.79	0.50	2.17	2.67	0.32	2.99	3.00	1.72	0.16
0.99	16.96	0.49	2.18	2.67	0.32	2.99	3.00	1.70	0.15

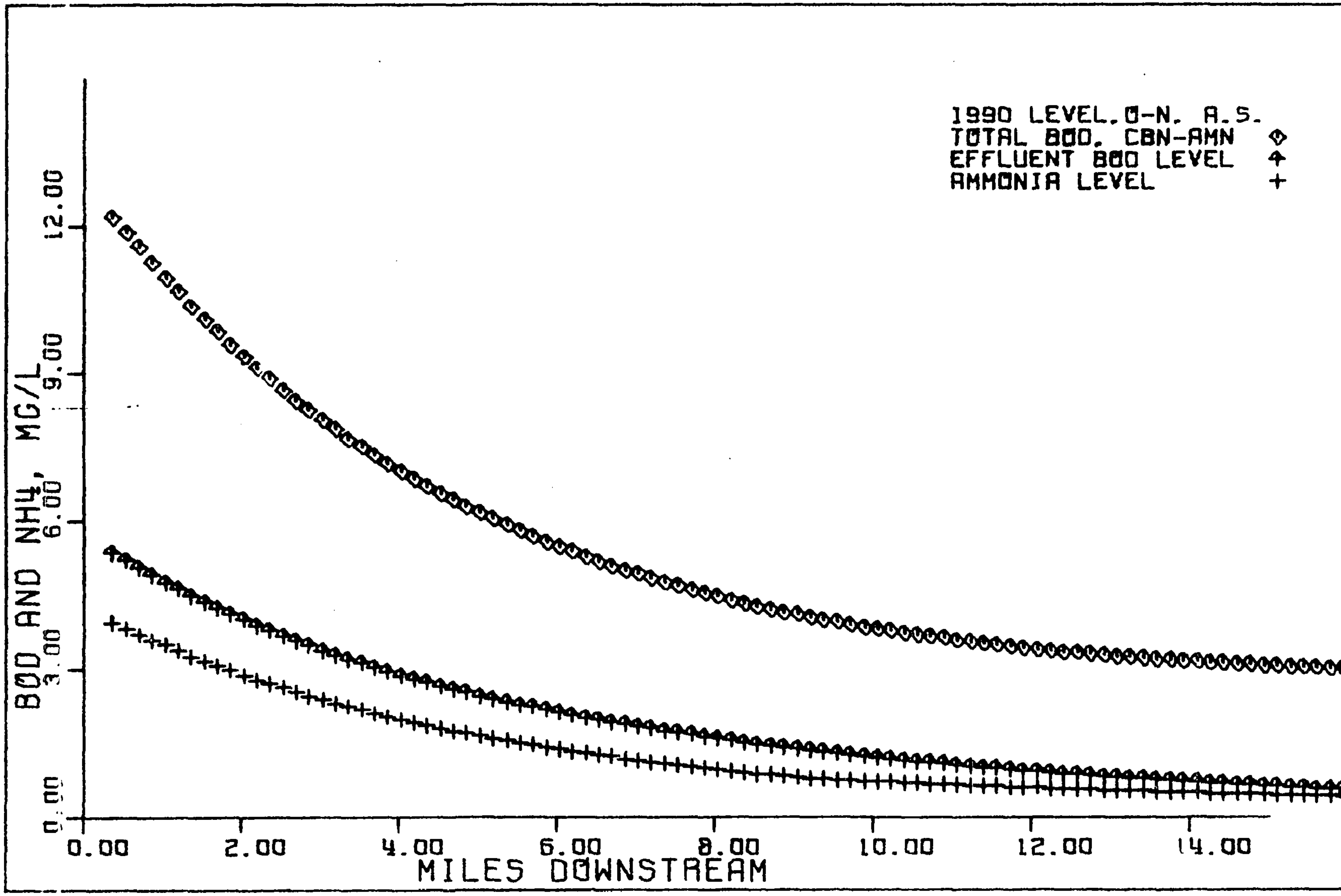
WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : OCT-NOV
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	9.24	0.37	0.0	5.68	0.37	0.0
MINIMUM DO, MG/L	8.18	1.87	0.09	2.61	5.54	0.31
FINAL DO, MG/L	11.70	13.75	0.80	3.60	13.75	0.80
DO DEFICIT						
INITIAL, MG/L	-0.74	0.37	0.0	4.13	0.37	0.0
FINAL, MG/L	-3.42	13.75	0.80	6.25	13.75	0.80
RIVER DISCHARGE						
INITIAL, CFS	61.13	0.37	0.0	61.13	0.37	0.0
FINAL, CFS	63.14	13.75	0.80	63.14	13.75	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	70.63	0.37	0.0	58.36	0.37	0.0
FINAL, DEG F	72.98	13.75	0.80	58.00	13.75	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	5.36	0.37	0.0	5.36	0.37	0.0
FINAL BOD, MG/L	0.53	13.75	0.80	0.94	13.75	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.73	13.75	0.80	2.18	13.75	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	5.43	0.37	0.0	5.43	0.37	0.0
FINAL BOD, MG/L	0.18	13.75	0.80	0.85	13.75	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	11.95	0.37	0.0	12.43	0.37	0.0
FINAL VALUE, MG/L	2.43	13.75	0.80	3.98	13.75	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	3.97	0.37	0.0	3.97	0.37	0.0
FINAL VALUE, MG/L	0.40	13.75	0.80	0.62	13.75	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.36	0.37	0.0	3.36	0.37	0.0
FINAL VALUE, MG/L	3.00	13.75	0.80	3.00	13.75	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.88	0.37	0.0	4.88	0.37	0.0
FINAL VALUE, MG/L	1.55	13.75	0.80	2.59	13.75	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	18.29	0.37	0.0	18.29	0.37	0.0
FINAL PERCENT	0.10	13.75	0.80	0.49	13.75	0.80


1990 LEVEL.O-N. A.S.
DAYTIME RESULTS
AVG. DAY & NIGHT
NIGHT RESULTS
D.O. LEVEL, MG/L
12.00
9.00
6.00
3.00
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM


1990 LEVEL.O-N. A.S.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
MILES DOWNSTREAM

I. Computer Results for 1990 Design Level, Activated Sludge and Ames Reservoir, Winter, 10 Yr, Low Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
5.88	50.00	25.00	0.0	29.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                 AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

    INPUT DATA FOR THIS ANALYSIS

    STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
    RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
    SEASON : WINTER

 GAMMA1 =   0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
   OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
   CYCLE NO.  1
   BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
        ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
   FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
        EFFLUENT Q =   9.10 CFS, RIVER Q =  50.00 CFS, TOTAL Q =  59.10 CFS
        CYCLE INCREMENT IS  0.0  CFS
   FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
        CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		50.0	12.79	9.95		0.40
0.0	0.37	34.8	34.8	34.8	59.1	11.24	8.84	10.04	4.19
0.02	0.70	34.5	34.5	34.5	59.1	11.14	9.08	10.11	4.12
0.04	1.03	34.2	34.2	34.2	59.2	11.07	9.29	10.18	4.05
0.06	1.36	34.0	34.0	34.0	59.2	11.03	9.49	10.26	3.98
0.08	1.68	33.7	33.7	33.7	59.2	11.00	9.67	10.33	3.91
0.10	2.01	33.6	33.6	33.6	59.3	10.98	9.83	10.41	3.85
0.12	2.34	33.4	33.4	33.4	59.3	10.98	9.99	10.49	3.79
0.14	2.67	33.2	33.2	33.2	59.3	10.99	10.13	10.56	3.72
0.16	3.00	33.1	33.1	33.1	59.4	11.01	10.26	10.64	3.66
0.18	3.33	33.0	33.0	33.0	59.4	11.04	10.39	10.71	3.61
0.20	3.66	32.9	32.9	32.9	59.4	11.06	10.50	10.78	3.55
0.22	3.99	32.8	32.8	32.8	59.5	11.10	10.61	10.85	3.49
0.24	4.32	32.7	32.7	32.7	59.5	11.14	10.71	10.92	3.44
0.26	4.65	32.6	32.6	32.6	59.5	11.18	10.81	10.99	3.38
0.28	4.97	32.6	32.6	32.6	59.6	11.22	10.90	11.06	3.33
0.30	5.30	32.5	32.5	32.5	59.6	11.26	10.98	11.12	3.28
0.32	5.63	32.4	32.4	32.4	59.6	10.95	10.68	10.82	3.23
0.34	5.96	32.4	32.4	32.4	59.7	10.65	10.38	10.52	3.18
0.36	6.29	32.3	32.3	32.3	59.7	10.36	10.09	10.23	3.13
0.38	6.62	32.3	32.3	32.3	59.7	10.08	9.81	9.94	3.08
0.40	6.95	32.3	32.3	32.3	59.8	9.81	9.54	9.67	3.03
0.42	7.28	32.2	32.2	32.2	59.8	9.54	9.27	9.40	2.98
0.44	7.61	32.2	32.2	32.2	59.8	9.28	9.01	9.15	2.94
0.46	7.94	32.2	32.2	32.2	59.9	9.03	8.76	8.89	2.89
0.48	8.27	32.2	32.2	32.2	59.9	8.78	8.52	8.65	2.85
0.50	8.60	32.2	32.2	32.2	59.9	8.55	8.28	8.41	2.80

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.93	32.1	32.1	32.1	60.0	8.32	8.05	8.19	2.76
0.54	9.26	32.1	32.1	32.1	60.0	8.09	7.83	7.96	2.72
0.56	9.59	32.1	32.1	32.1	60.0	7.88	7.62	7.75	2.68
0.58	9.92	32.1	32.1	32.1	60.1	7.66	7.41	7.54	2.64
0.60	10.25	32.1	32.1	32.1	60.1	7.46	7.21	7.33	2.60
0.62	10.58	32.1	32.1	32.1	60.1	7.26	7.01	7.14	2.56
0.64	10.91	32.1	32.1	32.1	60.2	7.07	6.82	6.95	2.52
0.66	11.24	32.1	32.1	32.1	60.2	6.89	6.64	6.76	2.48
0.68	11.58	32.1	32.1	32.1	60.2	6.71	6.46	6.58	2.44
0.70	11.91	32.0	32.0	32.0	60.3	6.53	6.29	6.41	2.40
0.72	12.24	32.0	32.0	32.0	60.3	6.36	6.12	6.24	2.37
0.74	12.57	32.0	32.0	32.0	60.3	6.20	5.96	6.08	2.33
0.76	12.90	32.0	32.0	32.0	60.4	6.04	5.80	5.92	2.29
0.78	13.23	32.0	32.0	32.0	60.4	5.89	5.65	5.77	2.26
0.80	13.56	32.0	32.0	32.0	60.4	5.74	5.50	5.62	2.23
0.82	13.89	32.0	32.0	32.0	60.5	5.59	5.36	5.48	2.19
0.84	14.22	32.0	32.0	32.0	60.5	5.45	5.22	5.34	2.16
0.86	14.55	32.0	32.0	32.0	60.5	5.32	5.09	5.20	2.13
0.88	14.89	32.0	32.0	32.0	60.6	5.19	4.96	5.07	2.09
0.90	15.22	32.0	32.0	32.0	60.6	5.06	4.83	4.95	2.06
0.92	15.55	32.0	32.0	32.0	60.6	4.94	4.71	4.82	2.03
0.94	15.88	32.0	32.0	32.0	60.7	4.82	4.59	4.70	2.00
0.96	16.21	32.0	32.0	32.0	60.7	4.70	4.48	4.59	1.97
0.98	16.54	32.0	32.0	32.0	60.7	4.59	4.37	4.48	1.94
1.00	16.88	32.0	32.0	32.0	60.8	4.48	4.26	4.37	1.91
1.02	17.21	32.0	32.0	32.0	60.8	4.38	4.16	4.27	1.88

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	17.54	32.0	32.0	32.0	60.8	4.27	4.06	4.17	1.85
1.06	17.87	32.0	32.0	32.0	60.9	4.18	3.96	4.07	1.82
1.08	18.20	32.0	32.0	32.0	60.9	4.08	3.87	3.98	1.79
1.10	18.54	32.0	32.0	32.0	60.9	3.99	3.78	3.88	1.77
1.12	18.87	32.0	32.0	32.0	61.0	3.90	3.69	3.80	1.74
1.14	19.20	32.0	32.0	32.0	61.0	3.81	3.61	3.71	1.71
1.16	19.53	32.0	32.0	32.0	61.0	3.73	3.52	3.63	1.69
1.18	19.87	32.0	32.0	32.0	61.1	3.65	3.44	3.55	1.66
1.20	20.20	32.0	32.0	32.0	61.1	3.57	3.37	3.47	1.64
1.22	20.53	32.0	32.0	32.0	61.1	3.49	3.29	3.39	1.61
1.24	20.86	32.0	32.0	32.0	61.2	3.42	3.22	3.32	1.59
1.26	21.20	32.0	32.0	32.0	61.2	3.35	3.15	3.25	1.56
1.28	21.53	32.0	32.0	32.0	61.2	3.28	3.08	3.18	1.54
1.30	21.86	32.0	32.0	32.0	61.3	3.21	3.02	3.11	1.52
1.32	22.19	32.0	32.0	32.0	61.3	3.15	2.95	3.05	1.49
1.34	22.53	32.0	32.0	32.0	61.3	3.08	2.89	2.99	1.47
1.36	22.86	32.0	32.0	32.0	61.4	3.02	2.83	2.93	1.45
1.38	23.19	32.0	32.0	32.0	61.4	2.96	2.77	2.87	1.43
1.40	23.53	32.0	32.0	32.0	61.4	2.90	2.72	2.81	1.40
1.42	23.86	32.0	32.0	32.0	61.5	2.85	2.66	2.76	1.38
1.44	24.19	32.0	32.0	32.0	61.5	2.79	2.61	2.70	1.36
1.46	24.53	32.0	32.0	32.0	61.5	2.74	2.56	2.65	1.34
1.48	24.86	32.0	32.0	32.0	61.6	2.69	2.51	2.60	1.32
1.50	25.19	32.0	32.0	32.0	61.6	2.64	2.46	2.55	1.30
1.52	25.53	32.0	32.0	32.0	61.6	2.59	2.41	2.50	1.28
1.54	25.86	32.0	32.0	32.0	61.7	2.54	2.37	2.45	1.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	26.19	32.0	32.0	32.0	61.7	2.50	2.32	2.41	1.24
1.58	26.53	32.0	32.0	32.0	61.7	2.45	2.28	2.37	1.22
1.60	26.86	32.0	32.0	32.0	61.8	2.41	2.24	2.32	1.21
1.62	27.19	32.0	32.0	32.0	61.8	2.36	2.20	2.28	1.19
1.64	27.53	32.0	32.0	32.0	61.8	2.32	2.16	2.24	1.17
1.66	27.86	32.0	32.0	32.0	61.9	2.28	2.12	2.20	1.15
1.68	28.20	32.0	32.0	32.0	61.9	2.24	2.08	2.16	1.13
1.70	28.53	32.0	32.0	32.0	61.9	2.20	2.04	2.12	1.12
1.72	28.87	32.0	32.0	32.0	62.0	2.16	2.00	2.08	1.10
1.74	29.20	32.0	32.0	32.0	62.0	2.13	1.97	2.05	1.08
1.76	29.53	32.0	32.0	32.0	62.0	2.09	1.93	2.01	1.07
1.78	29.87	32.0	32.0	32.0	62.1	2.05	1.90	1.97	1.05
1.80	30.20	32.0	32.0	32.0	62.1	2.02	1.86	1.94	1.04
1.82	30.54	32.0	32.0	32.0	62.1	1.98	1.83	1.91	1.02
1.84	30.87	32.0	32.0	32.0	62.2	1.95	1.80	1.87	1.01
1.86	31.21	32.0	32.0	32.0	62.2	1.91	1.77	1.84	0.99
1.88	31.54	32.0	32.0	32.0	62.2	1.88	1.74	1.81	0.98
1.90	31.88	32.0	32.0	32.0	62.3	1.85	1.71	1.78	0.96
1.92	32.21	32.0	32.0	32.0	62.3	1.81	1.68	1.75	0.95
1.94	32.55	32.0	32.0	32.0	62.3	1.78	1.65	1.72	0.94
1.96	32.88	32.0	32.0	32.0	62.4	1.75	1.62	1.69	0.92
1.98	33.22	32.0	32.0	32.0	62.4	1.72	1.59	1.66	0.91

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.67	2.67	0.55	3.22	3.00	0.40	0.10
0.0	0.37	7.63	0.75	8.39	5.73	14.12	3.31	4.96	15.49
0.02	0.70	7.44	0.78	8.22	5.63	13.85	3.29	4.93	14.75
0.04	1.03	7.23	0.80	8.03	5.54	13.57	3.27	4.90	14.06
0.06	1.36	7.03	0.82	7.85	5.44	13.29	3.25	4.87	13.41
0.08	1.68	6.84	0.84	7.68	5.35	13.03	3.23	4.84	12.79
0.10	2.01	6.66	0.86	7.51	5.27	12.78	3.21	4.81	12.20
0.12	2.34	6.48	0.88	7.35	5.18	12.53	3.19	4.79	11.64
0.14	2.67	6.30	0.90	7.20	5.10	12.29	3.17	4.76	11.11
0.16	3.00	6.14	0.92	7.05	5.01	12.07	3.14	4.73	10.61
0.18	3.33	5.98	0.94	6.91	4.93	11.84	3.12	4.70	10.13
0.20	3.66	5.82	0.95	6.78	4.85	11.63	3.10	4.68	9.67
0.22	3.99	5.67	0.97	6.64	4.78	11.42	3.08	4.65	9.24
0.24	4.32	5.52	0.99	6.52	4.70	11.22	3.06	4.62	8.82
0.26	4.65	5.38	1.01	6.40	4.63	11.02	3.04	4.60	8.43
0.28	4.97	5.25	1.03	6.28	4.56	10.83	3.02	4.57	8.05
0.30	5.30	5.11	1.05	6.17	4.48	10.65	3.00	4.55	7.70
0.32	5.63	4.98	1.07	6.06	4.41	10.47	3.00	4.52	7.35
0.34	5.96	4.86	1.09	5.95	4.35	10.30	3.00	4.50	7.03
0.36	6.29	4.74	1.11	5.85	4.28	10.13	3.00	4.47	6.72
0.38	6.62	4.62	1.13	5.75	4.21	9.96	3.00	4.45	6.42
0.40	6.95	4.51	1.15	5.66	4.15	9.80	3.00	4.42	6.13
0.42	7.28	4.40	1.17	5.57	4.08	9.65	3.00	4.40	5.86
0.44	7.61	4.29	1.19	5.48	4.02	9.50	3.00	4.38	5.60
0.46	7.94	4.18	1.21	5.39	3.96	9.35	3.00	4.35	5.36
0.48	8.27	4.08	1.23	5.31	3.90	9.21	3.00	4.33	5.12
0.50	8.60	3.98	1.25	5.23	3.84	9.07	3.00	4.30	4.90

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.93	3.89	1.27	5.15	3.78	8.93	3.00	4.28	4.68
0.54	9.26	3.80	1.29	5.08	3.72	8.80	3.00	4.26	4.47
0.56	9.59	3.70	1.30	5.01	3.66	8.67	3.00	4.23	4.28
0.58	9.92	3.62	1.32	4.94	3.61	8.55	3.00	4.21	4.09
0.60	10.25	3.53	1.34	4.87	3.55	8.42	3.00	4.19	3.91
0.62	10.58	3.45	1.36	4.81	3.50	8.31	3.00	4.16	3.74
0.64	10.91	3.37	1.38	4.75	3.44	8.19	3.00	4.14	3.57
0.66	11.24	3.29	1.40	4.69	3.39	8.08	3.00	4.12	3.42
0.68	11.58	3.21	1.42	4.63	3.34	7.97	3.00	4.10	3.27
0.70	11.91	3.13	1.44	4.57	3.29	7.86	3.00	4.07	3.12
0.72	12.24	3.06	1.46	4.52	3.24	7.76	3.00	4.05	2.99
0.74	12.57	2.99	1.48	4.47	3.19	7.65	3.00	4.03	2.85
0.76	12.90	2.92	1.49	4.42	3.14	7.55	3.00	4.01	2.73
0.78	13.23	2.85	1.51	4.37	3.09	7.46	3.00	3.99	2.61
0.80	13.56	2.79	1.53	4.32	3.04	7.36	3.00	3.97	2.49
0.82	13.89	2.72	1.55	4.28	3.00	7.27	3.00	3.94	2.39
0.84	14.22	2.66	1.57	4.23	2.95	7.18	3.00	3.92	2.28
0.86	14.55	2.60	1.59	4.19	2.91	7.10	3.00	3.90	2.18
0.88	14.89	2.54	1.61	4.15	2.86	7.01	3.00	3.88	2.08
0.90	15.22	2.48	1.63	4.11	2.82	6.93	3.00	3.86	1.99
0.92	15.55	2.43	1.64	4.07	2.78	6.85	3.00	3.84	1.91
0.94	15.88	2.37	1.66	4.04	2.73	6.77	3.00	3.82	1.82
0.96	16.21	2.32	1.68	4.00	2.69	6.69	3.00	3.80	1.74
0.98	16.54	2.27	1.70	3.97	2.65	6.62	3.00	3.78	1.67
1.00	16.88	2.22	1.72	3.94	2.61	6.55	3.00	3.76	1.59
1.02	17.21	2.17	1.74	3.91	2.57	6.48	3.00	3.74	1.52

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	17.54	2.12	1.76	3.88	2.53	6.41	3.00	3.71	1.46
1.06	17.87	2.07	1.78	3.85	2.49	6.34	3.00	3.69	1.39
1.08	18.20	2.03	1.79	3.82	2.46	6.28	3.00	3.67	1.33
1.10	18.54	1.98	1.81	3.79	2.42	6.21	3.00	3.65	1.27
1.12	18.87	1.94	1.83	3.77	2.38	6.15	3.00	3.63	1.22
1.14	19.20	1.89	1.85	3.75	2.34	6.09	3.00	3.62	1.16
1.16	19.53	1.85	1.87	3.72	2.31	6.03	3.00	3.60	1.11
1.18	19.87	1.81	1.89	3.70	2.27	5.97	3.00	3.58	1.06
1.20	20.20	1.77	1.91	3.68	2.24	5.92	3.00	3.56	1.02
1.22	20.53	1.73	1.93	3.66	2.21	5.86	3.00	3.54	0.97
1.24	20.86	1.70	1.94	3.64	2.17	5.81	3.00	3.52	0.93
1.26	21.20	1.66	1.96	3.62	2.14	5.76	3.00	3.50	0.89
1.28	21.53	1.62	1.98	3.60	2.11	5.71	3.00	3.48	0.85
1.30	21.86	1.59	2.00	3.59	2.07	5.66	3.00	3.46	0.81
1.32	22.19	1.55	2.02	3.57	2.04	5.61	3.00	3.44	0.78
1.34	22.53	1.52	2.04	3.56	2.01	5.57	3.00	3.42	0.74
1.36	22.86	1.49	2.06	3.54	1.98	5.52	3.00	3.41	0.71
1.38	23.19	1.45	2.07	3.53	1.95	5.48	3.00	3.39	0.68
1.40	23.53	1.42	2.09	3.52	1.92	5.44	3.00	3.37	0.65
1.42	23.86	1.39	2.11	3.50	1.89	5.40	3.00	3.35	0.62
1.44	24.19	1.36	2.13	3.49	1.86	5.36	3.00	3.33	0.59
1.46	24.53	1.33	2.15	3.48	1.84	5.32	3.00	3.31	0.57
1.48	24.86	1.31	2.17	3.47	1.81	5.28	3.00	3.30	0.54
1.50	25.19	1.28	2.19	3.46	1.78	5.24	3.00	3.28	0.52
1.52	25.53	1.25	2.20	3.45	1.75	5.21	3.00	3.26	0.50
1.54	25.86	1.22	2.22	3.45	1.73	5.17	3.00	3.24	0.48

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

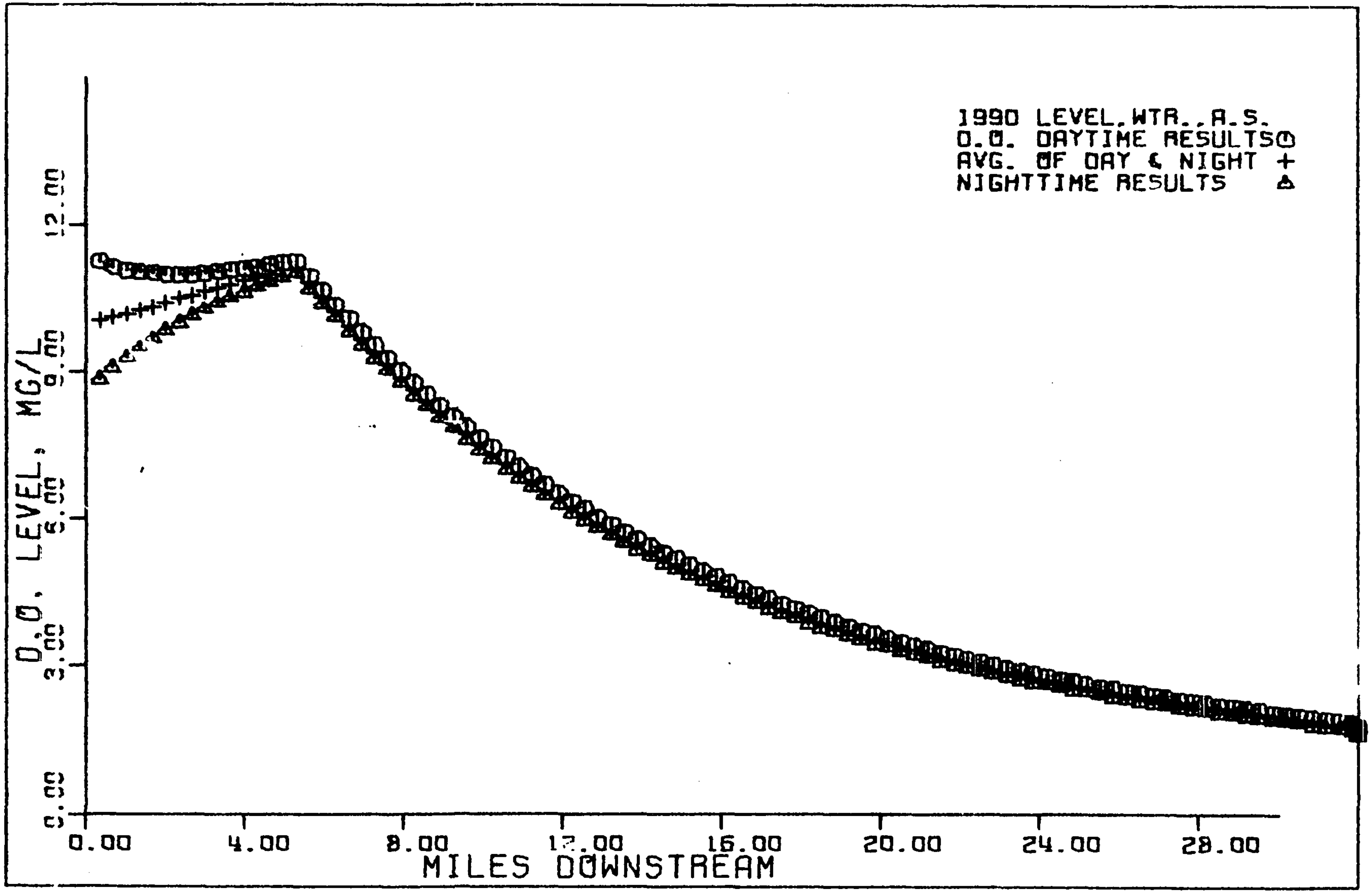
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	26.19	1.20	2.24	3.44	1.70	5.14	3.00	3.23	0.45
1.58	26.53	1.17	2.26	3.43	1.67	5.11	3.00	3.21	0.43
1.60	26.86	1.15	2.28	3.43	1.65	5.07	3.00	3.19	0.42
1.62	27.19	1.12	2.30	3.42	1.62	5.04	3.00	3.17	0.40
1.64	27.53	1.10	2.31	3.41	1.60	5.01	3.00	3.16	0.38
1.66	27.86	1.08	2.33	3.41	1.58	4.98	3.00	3.14	0.36
1.68	28.20	1.05	2.35	3.41	1.55	4.96	3.00	3.12	0.35
1.70	28.53	1.03	2.37	3.40	1.53	4.93	3.00	3.11	0.33
1.72	28.87	1.01	2.39	3.40	1.50	4.90	3.00	3.09	0.32
1.74	29.20	0.99	2.41	3.40	1.48	4.88	3.00	3.07	0.30
1.76	29.53	0.97	2.42	3.39	1.46	4.85	3.00	3.06	0.29
1.78	29.87	0.95	2.44	3.39	1.44	4.83	3.00	3.04	0.28
1.80	30.20	0.93	2.46	3.39	1.42	4.81	3.00	3.02	0.27
1.82	30.54	0.91	2.48	3.39	1.40	4.78	3.00	3.01	0.25
1.84	30.87	0.89	2.50	3.39	1.37	4.76	3.00	2.99	0.24
1.86	31.21	0.87	2.52	3.39	1.36	4.74	3.00	2.97	0.23
1.88	31.54	0.85	2.53	3.39	1.34	4.72	3.00	2.96	0.22
1.90	31.88	0.84	2.55	3.39	1.32	4.70	3.00	2.94	0.21
1.92	32.21	0.82	2.57	3.39	1.30	4.69	3.00	2.93	0.20
1.94	32.55	0.80	2.59	3.39	1.28	4.67	3.00	2.91	0.19
1.96	32.88	0.78	2.61	3.39	1.26	4.65	3.00	2.89	0.19
1.98	33.22	0.77	2.63	3.39	1.25	4.64	3.00	2.88	0.18

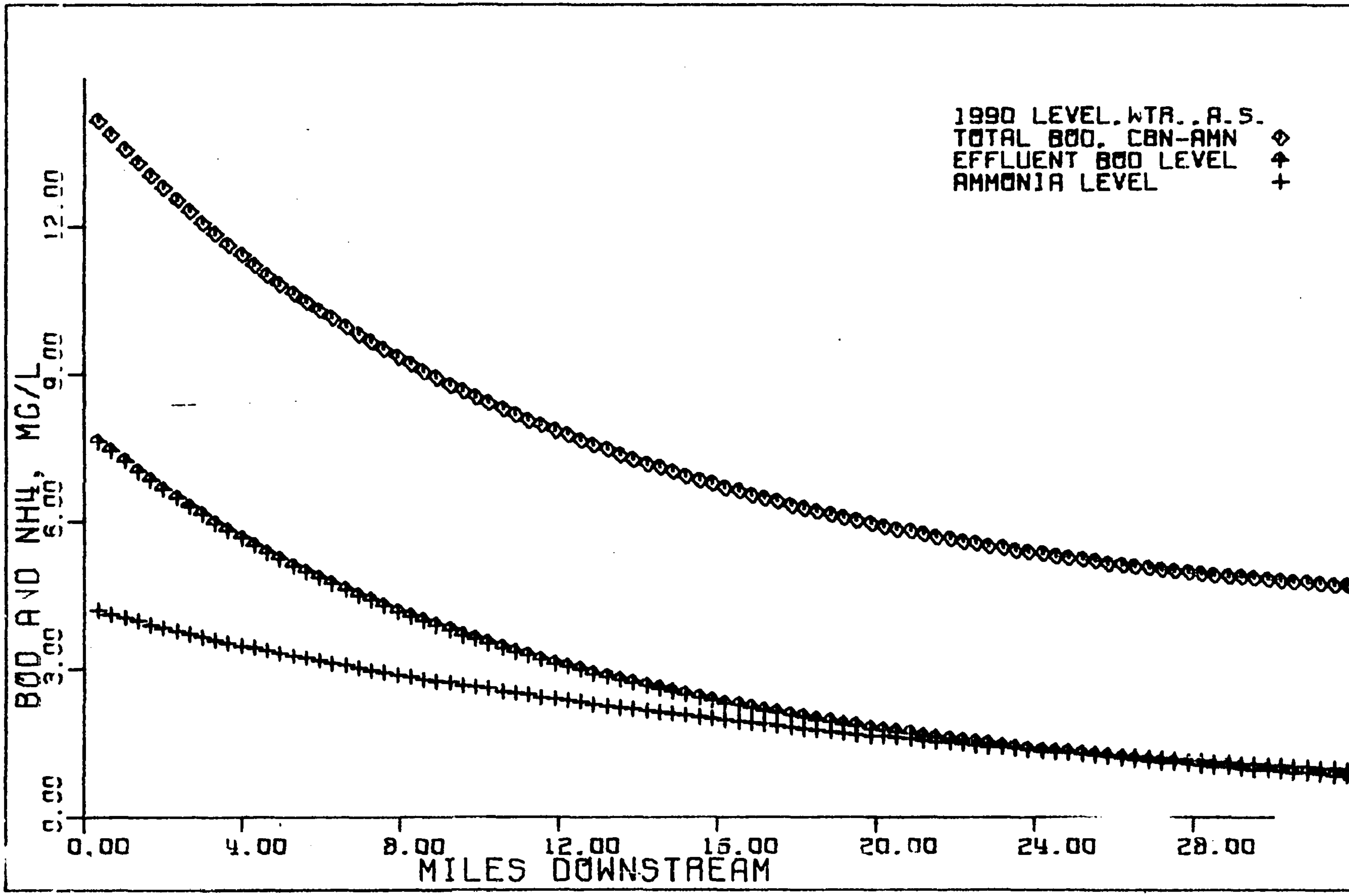
WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	11.24	0.37	0.0	8.84	0.37	0.0
MINIMUM DO, MG/L	1.72	33.22	1.98	1.59	33.22	1.98
FINAL DO, MG/L	5.74	13.56	0.80	5.50	13.56	0.80
DO DEFICIT						
INITIAL, MG/L	2.38	0.37	0.0	4.78	0.37	0.0
FINAL, MG/L	8.47	13.56	0.80	8.71	13.56	0.80
RIVER DISCHARGE						
INITIAL, CFS	59.10	0.37	0.0	59.10	0.37	0.0
FINAL, CFS	60.42	13.56	0.80	60.42	13.56	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	34.77	0.37	0.0	34.77	0.37	0.0
FINAL, DEG F	32.03	13.56	0.80	32.03	13.56	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	7.63	0.37	0.0	7.63	0.37	0.0
FINAL BOD, MG/L	2.78	13.56	0.80	2.79	13.56	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.50	13.56	0.80	1.56	13.56	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	5.73	0.37	0.0	5.73	0.37	0.0
FINAL BOD, MG/L	3.04	13.56	0.80	3.04	13.56	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	14.04	0.37	0.0	14.20	0.37	0.0
FINAL VALUE, MG/L	7.33	13.56	0.80	7.40	13.56	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	4.19	0.37	0.0	4.19	0.37	0.0
FINAL VALUE, MG/L	2.23	13.56	0.80	2.23	13.56	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.31	0.37	0.0	3.31	0.37	0.0
FINAL VALUE, MG/L	3.00	13.56	0.80	3.00	13.56	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.96	0.37	0.0	4.96	0.37	0.0
FINAL VALUE, MG/L	3.97	13.56	0.80	3.97	13.56	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	15.49	0.37	0.0	15.49	0.37	0.0
FINAL PERCENT	2.49	13.56	0.80	2.49	13.56	0.80


1990 LEVEL.WTR..A.S.
D.O. DAYTIME RESULTS O
AVG. OF DAY & NIGHT +
NIGHTTIME RESULTS Δ
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM



1990 LEVEL.WTR..A.S.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM

J. Computer Results for 1990 Design Level, Activated Sludge and Ames Reservoir, Winter, 10 Yr, High Reaeration Coefficient

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
5.88	50.00	25.00	0.0	29.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.300	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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                    AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION     IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
     SEASON : WINTER

 GAMMA1 =    0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    9.10 CFS, RIVER Q =  50.00 CFS, TOTAL Q =  59.10 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		50.0	12.79	9.95		0.40
0.0	0.37	34.8	34.8	34.8	59.1	11.24	8.84	10.04	4.19
0.02	0.70	34.5	34.5	34.5	59.1	11.14	9.08	10.11	4.12
0.04	1.03	34.2	34.2	34.2	59.2	11.07	9.29	10.18	4.05
0.06	1.36	34.0	34.0	34.0	59.2	11.03	9.49	10.26	3.98
0.08	1.68	33.7	33.7	33.7	59.2	11.00	9.67	10.33	3.91
0.10	2.01	33.6	33.6	33.6	59.3	10.98	9.83	10.41	3.85
0.12	2.34	33.4	33.4	33.4	59.3	10.98	9.99	10.49	3.79
0.14	2.67	33.2	33.2	33.2	59.3	10.99	10.13	10.56	3.72
0.16	3.00	33.1	33.1	33.1	59.4	11.01	10.26	10.64	3.66
0.18	3.33	33.0	33.0	33.0	59.4	11.04	10.39	10.71	3.61
0.20	3.66	32.9	32.9	32.9	59.4	11.06	10.50	10.78	3.55
0.22	3.99	32.8	32.8	32.8	59.5	11.10	10.61	10.85	3.49
0.24	4.32	32.7	32.7	32.7	59.5	11.14	10.71	10.92	3.44
0.26	4.65	32.6	32.6	32.6	59.5	11.18	10.81	10.99	3.38
0.28	4.97	32.6	32.6	32.6	59.6	11.22	10.90	11.06	3.33
0.30	5.30	32.5	32.5	32.5	59.6	11.26	10.98	11.12	3.28
0.32	5.63	32.4	32.4	32.4	59.6	10.97	10.69	10.83	3.23
0.34	5.96	32.4	32.4	32.4	59.7	10.68	10.41	10.55	3.18
0.36	6.29	32.3	32.3	32.3	59.7	10.41	10.14	10.27	3.13
0.38	6.62	32.3	32.3	32.3	59.7	10.14	9.87	10.01	3.08
0.40	6.95	32.3	32.3	32.3	59.8	9.88	9.62	9.75	3.03
0.42	7.28	32.2	32.2	32.2	59.8	9.64	9.37	9.50	2.98
0.44	7.61	32.2	32.2	32.2	59.8	9.40	9.14	9.27	2.94
0.46	7.94	32.2	32.2	32.2	59.9	9.16	8.91	9.04	2.89
0.48	8.27	32.2	32.2	32.2	59.9	8.94	8.69	8.82	2.85
0.50	8.60	32.2	32.2	32.2	59.9	8.73	8.48	8.60	2.80

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.93	32.1	32.1	32.1	60.0	8.52	8.27	8.40	2.76
0.54	9.26	32.1	32.1	32.1	60.0	8.32	8.08	8.20	2.72
0.56	9.59	32.1	32.1	32.1	60.0	8.13	7.89	8.01	2.68
0.58	9.92	32.1	32.1	32.1	60.1	7.94	7.70	7.82	2.64
0.60	10.25	32.1	32.1	32.1	60.1	7.77	7.53	7.65	2.60
0.62	10.58	32.1	32.1	32.1	60.1	7.59	7.36	7.48	2.56
0.64	10.91	32.1	32.1	32.1	60.2	7.43	7.20	7.31	2.52
0.66	11.24	32.1	32.1	32.1	60.2	7.27	7.04	7.16	2.48
0.68	11.58	32.1	32.1	32.1	60.2	7.12	6.89	7.01	2.44
0.70	11.91	32.0	32.0	32.0	60.3	6.97	6.75	6.86	2.40
0.72	12.24	32.0	32.0	32.0	60.3	6.83	6.61	6.72	2.37
0.74	12.57	32.0	32.0	32.0	60.3	6.70	6.48	6.59	2.33
0.76	12.90	32.0	32.0	32.0	60.4	6.57	6.35	6.46	2.29
0.78	13.23	32.0	32.0	32.0	60.4	6.45	6.23	6.34	2.26
0.80	13.56	32.0	32.0	32.0	60.4	6.33	6.12	6.22	2.23
0.82	13.89	32.0	32.0	32.0	60.5	6.21	6.00	6.11	2.19
0.84	14.22	32.0	32.0	32.0	60.5	6.10	5.90	6.00	2.16
0.86	14.55	32.0	32.0	32.0	60.5	6.00	5.80	5.90	2.13
0.88	14.89	32.0	32.0	32.0	60.6	5.90	5.70	5.80	2.09
0.90	15.22	32.0	32.0	32.0	60.6	5.80	5.60	5.70	2.06
0.92	15.55	32.0	32.0	32.0	60.6	5.71	5.52	5.61	2.03
0.94	15.88	32.0	32.0	32.0	60.7	5.62	5.43	5.53	2.00
0.96	16.21	32.0	32.0	32.0	60.7	5.54	5.35	5.44	1.97
0.98	16.54	32.0	32.0	32.0	60.7	5.46	5.27	5.37	1.94
1.00	16.88	32.0	32.0	32.0	60.8	5.38	5.20	5.29	1.91
1.02	17.21	32.0	32.0	32.0	60.8	5.31	5.13	5.22	1.88

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	17.54	32.0	32.0	32.0	60.8	5.24	5.06	5.15	1.85
1.06	17.87	32.0	32.0	32.0	60.9	5.17	4.99	5.08	1.82
1.08	18.20	32.0	32.0	32.0	60.9	5.11	4.93	5.02	1.79
1.10	18.54	32.0	32.0	32.0	60.9	5.05	4.87	4.96	1.77
1.12	18.87	32.0	32.0	32.0	61.0	4.99	4.82	4.91	1.74
1.14	19.20	32.0	32.0	32.0	61.0	4.94	4.77	4.85	1.71
1.16	19.53	32.0	32.0	32.0	61.0	4.89	4.72	4.80	1.69
1.18	19.87	32.0	32.0	32.0	61.1	4.84	4.67	4.75	1.66
1.20	20.20	32.0	32.0	32.0	61.1	4.79	4.62	4.71	1.64
1.22	20.53	32.0	32.0	32.0	61.1	4.74	4.58	4.66	1.61
1.24	20.86	32.0	32.0	32.0	61.2	4.70	4.54	4.62	1.59
1.26	21.20	32.0	32.0	32.0	61.2	4.66	4.50	4.58	1.56
1.28	21.53	32.0	32.0	32.0	61.2	4.62	4.47	4.54	1.54
1.30	21.86	32.0	32.0	32.0	61.3	4.59	4.43	4.51	1.52
1.32	22.19	32.0	32.0	32.0	61.3	4.55	4.40	4.48	1.49
1.34	22.53	32.0	32.0	32.0	61.3	4.52	4.37	4.44	1.47
1.36	22.86	32.0	32.0	32.0	61.4	4.49	4.34	4.41	1.45
1.38	23.19	32.0	32.0	32.0	61.4	4.46	4.31	4.39	1.43
1.40	23.53	32.0	32.0	32.0	61.4	4.43	4.29	4.36	1.40
1.42	23.86	32.0	32.0	32.0	61.5	4.41	4.26	4.33	1.38
1.44	24.19	32.0	32.0	32.0	61.5	4.38	4.24	4.31	1.36
1.46	24.53	32.0	32.0	32.0	61.5	4.36	4.22	4.29	1.34
1.48	24.86	32.0	32.0	32.0	61.6	4.34	4.20	4.27	1.32
1.50	25.19	32.0	32.0	32.0	61.6	4.32	4.18	4.25	1.30
1.52	25.53	32.0	32.0	32.0	61.6	4.30	4.16	4.23	1.28
1.54	25.86	32.0	32.0	32.0	61.7	4.28	4.14	4.21	1.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	26.19	32.0	32.0	32.0	61.7	4.26	4.13	4.19	1.24
1.58	26.53	32.0	32.0	32.0	61.7	4.24	4.11	4.18	1.22
1.60	26.86	32.0	32.0	32.0	61.8	4.23	4.10	4.16	1.21
1.62	27.19	32.0	32.0	32.0	61.8	4.21	4.09	4.15	1.19
1.64	27.53	32.0	32.0	32.0	61.8	4.20	4.08	4.14	1.17
1.66	27.86	32.0	32.0	32.0	61.9	4.19	4.06	4.13	1.15
1.68	28.20	32.0	32.0	32.0	61.9	4.17	4.05	4.11	1.13
1.70	28.53	32.0	32.0	32.0	61.9	4.16	4.04	4.10	1.12
1.72	28.87	32.0	32.0	32.0	62.0	4.15	4.03	4.09	1.10
1.74	29.20	32.0	32.0	32.0	62.0	4.14	4.02	4.08	1.08
1.76	29.53	32.0	32.0	32.0	62.0	4.13	4.01	4.07	1.07
1.78	29.87	32.0	32.0	32.0	62.1	4.12	4.01	4.06	1.05
1.80	30.20	32.0	32.0	32.0	62.1	4.11	4.00	4.05	1.03
1.82	30.54	32.0	32.0	32.0	62.1	4.10	3.99	4.05	1.02
1.84	30.87	32.0	32.0	32.0	62.2	4.09	3.98	4.04	1.00
1.86	31.21	32.0	32.0	32.0	62.2	4.08	3.97	4.03	0.99
1.88	31.54	32.0	32.0	32.0	62.2	4.07	3.97	4.02	0.97
1.90	31.88	32.0	32.0	32.0	62.3	4.06	3.96	4.01	0.96
1.92	32.21	32.0	32.0	32.0	62.3	4.06	3.95	4.00	0.94
1.94	32.55	32.0	32.0	32.0	62.3	4.05	3.95	4.00	0.93
1.96	32.88	32.0	32.0	32.0	62.4	4.04	3.94	3.99	0.92
1.98	33.22	32.0	32.0	32.0	62.4	4.03	3.93	3.98	0.90

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.67	2.67	0.55	3.22	3.00	0.40	0.10
0.0	0.37	7.63	0.75	8.39	5.73	14.12	3.31	4.96	15.49
0.02	0.70	7.44	0.78	8.22	5.63	13.85	3.29	4.93	14.75
0.04	1.03	7.23	0.80	8.03	5.54	13.57	3.27	4.90	14.06
0.06	1.36	7.03	0.82	7.85	5.44	13.29	3.25	4.87	13.41
0.08	1.68	6.84	0.84	7.68	5.35	13.03	3.23	4.84	12.79
0.10	2.01	6.66	0.86	7.51	5.27	12.78	3.21	4.81	12.20
0.12	2.34	6.48	0.88	7.35	5.18	12.53	3.19	4.79	11.64
0.14	2.67	6.30	0.90	7.20	5.10	12.30	3.17	4.76	11.11
0.16	3.00	6.14	0.92	7.05	5.01	12.07	3.14	4.73	10.61
0.18	3.33	5.98	0.94	6.91	4.93	11.84	3.12	4.70	10.13
0.20	3.66	5.82	0.95	6.78	4.85	11.63	3.10	4.68	9.67
0.22	3.99	5.67	0.97	6.64	4.78	11.42	3.08	4.65	9.24
0.24	4.32	5.52	0.99	6.52	4.70	11.22	3.06	4.62	8.82
0.26	4.65	5.38	1.01	6.40	4.63	11.02	3.04	4.60	8.43
0.28	4.97	5.25	1.03	6.28	4.56	10.84	3.02	4.57	8.05
0.30	5.30	5.11	1.05	6.17	4.48	10.65	3.00	4.55	7.70
0.32	5.63	4.98	1.07	6.06	4.41	10.47	3.00	4.52	7.35
0.34	5.96	4.86	1.09	5.95	4.35	10.30	3.00	4.50	7.03
0.36	6.29	4.74	1.11	5.85	4.28	10.13	3.00	4.47	6.72
0.38	6.62	4.62	1.13	5.75	4.21	9.96	3.00	4.45	6.42
0.40	6.95	4.51	1.15	5.66	4.15	9.80	3.00	4.42	6.13
0.42	7.28	4.40	1.17	5.57	4.08	9.65	3.00	4.40	5.86
0.44	7.61	4.29	1.19	5.48	4.02	9.50	3.00	4.38	5.60
0.46	7.94	4.18	1.21	5.39	3.96	9.35	3.00	4.35	5.36
0.48	8.27	4.08	1.23	5.31	3.90	9.21	3.00	4.33	5.12
0.50	8.60	3.98	1.25	5.23	3.84	9.07	3.00	4.30	4.90

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.93	3.89	1.27	5.15	3.78	8.93	3.00	4.28	4.68
0.54	9.26	3.80	1.29	5.08	3.72	8.80	3.00	4.26	4.47
0.56	9.59	3.70	1.30	5.01	3.66	8.67	3.00	4.23	4.28
0.58	9.92	3.62	1.32	4.94	3.61	8.55	3.00	4.21	4.09
0.60	10.25	3.53	1.34	4.87	3.55	8.42	3.00	4.19	3.91
0.62	10.58	3.45	1.36	4.81	3.50	8.31	3.00	4.16	3.74
0.64	10.91	3.37	1.38	4.75	3.44	8.19	3.00	4.14	3.57
0.66	11.24	3.29	1.40	4.69	3.39	8.08	3.00	4.12	3.42
0.68	11.58	3.21	1.42	4.63	3.34	7.97	3.00	4.10	3.27
0.70	11.91	3.13	1.44	4.57	3.29	7.86	3.00	4.07	3.12
0.72	12.24	3.06	1.46	4.52	3.24	7.76	3.00	4.05	2.99
0.74	12.57	2.99	1.48	4.47	3.19	7.65	3.00	4.03	2.85
0.76	12.90	2.92	1.49	4.42	3.14	7.55	3.00	4.01	2.73
0.78	13.23	2.85	1.51	4.37	3.09	7.46	3.00	3.99	2.61
0.80	13.56	2.79	1.53	4.32	3.04	7.36	3.00	3.97	2.49
0.82	13.89	2.72	1.55	4.28	3.00	7.27	3.00	3.94	2.39
0.84	14.22	2.66	1.57	4.23	2.95	7.18	3.00	3.92	2.28
0.86	14.55	2.60	1.59	4.19	2.91	7.10	3.00	3.90	2.18
0.88	14.89	2.54	1.61	4.15	2.86	7.01	3.00	3.88	2.08
0.90	15.22	2.48	1.63	4.11	2.82	6.93	3.00	3.86	1.99
0.92	15.55	2.43	1.65	4.07	2.78	6.85	3.00	3.84	1.91
0.94	15.88	2.37	1.66	4.04	2.73	6.77	3.00	3.82	1.82
0.96	16.21	2.32	1.68	4.00	2.69	6.69	3.00	3.80	1.74
0.98	16.54	2.27	1.70	3.97	2.65	6.62	3.00	3.78	1.67
1.00	16.88	2.22	1.72	3.94	2.61	6.55	3.00	3.76	1.59
1.02	17.21	2.17	1.74	3.91	2.57	6.48	3.00	3.74	1.52

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES., 10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	17.54	2.12	1.76	3.88	2.53	6.41	3.00	3.71	1.46
1.06	17.87	2.07	1.78	3.85	2.49	6.34	3.00	3.69	1.39
1.08	18.20	2.03	1.79	3.82	2.46	6.28	3.00	3.67	1.33
1.10	18.54	1.98	1.81	3.79	2.42	6.21	3.00	3.65	1.27
1.12	18.87	1.94	1.83	3.77	2.38	6.15	3.00	3.63	1.22
1.14	19.20	1.89	1.85	3.75	2.34	6.09	3.00	3.62	1.16
1.16	19.53	1.85	1.87	3.72	2.31	6.03	3.00	3.60	1.11
1.18	19.87	1.81	1.89	3.70	2.27	5.97	3.00	3.58	1.06
1.20	20.20	1.77	1.91	3.68	2.24	5.92	3.00	3.56	1.02
1.22	20.53	1.73	1.93	3.66	2.21	5.86	3.00	3.54	0.97
1.24	20.86	1.70	1.94	3.64	2.17	5.81	3.00	3.52	0.93
1.26	21.20	1.66	1.96	3.62	2.14	5.76	3.00	3.50	0.89
1.28	21.53	1.62	1.98	3.60	2.11	5.71	3.00	3.48	0.85
1.30	21.86	1.59	2.00	3.59	2.07	5.66	3.00	3.46	0.81
1.32	22.19	1.55	2.02	3.57	2.04	5.61	3.00	3.44	0.78
1.34	22.53	1.52	2.04	3.56	2.01	5.57	3.00	3.42	0.74
1.36	22.86	1.49	2.06	3.54	1.98	5.52	3.00	3.41	0.71
1.38	23.19	1.45	2.07	3.53	1.95	5.48	3.00	3.39	0.68
1.40	23.53	1.42	2.09	3.52	1.92	5.44	3.00	3.37	0.65
1.42	23.86	1.39	2.11	3.50	1.89	5.40	3.00	3.35	0.62
1.44	24.19	1.36	2.13	3.49	1.86	5.36	3.00	3.33	0.59
1.46	24.53	1.33	2.15	3.48	1.84	5.32	3.00	3.31	0.57
1.48	24.86	1.31	2.17	3.47	1.81	5.28	3.00	3.30	0.54
1.50	25.19	1.28	2.19	3.46	1.78	5.24	3.00	3.28	0.52
1.52	25.53	1.25	2.20	3.45	1.75	5.21	3.00	3.26	0.50
1.54	25.86	1.22	2.22	3.45	1.73	5.17	3.00	3.24	0.48

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	26.19	1.20	2.24	3.44	1.70	5.14	3.00	3.23	0.45
1.58	26.53	1.17	2.26	3.43	1.67	5.11	3.00	3.21	0.43
1.60	26.86	1.15	2.28	3.43	1.65	5.07	3.00	3.19	0.42
1.62	27.19	1.12	2.30	3.42	1.62	5.04	3.00	3.17	0.40
1.64	27.53	1.10	2.31	3.41	1.60	5.01	3.00	3.16	0.38
1.66	27.86	1.08	2.33	3.41	1.58	4.98	3.00	3.14	0.36
1.68	28.20	1.05	2.35	3.41	1.55	4.96	3.00	3.12	0.35
1.70	28.53	1.03	2.37	3.40	1.53	4.93	3.00	3.11	0.33
1.72	28.87	1.01	2.39	3.40	1.50	4.90	3.00	3.09	0.32
1.74	29.20	0.99	2.41	3.40	1.48	4.88	3.00	3.07	0.30
1.76	29.53	0.97	2.42	3.39	1.46	4.85	3.00	3.06	0.29
1.78	29.87	0.95	2.44	3.39	1.44	4.83	3.00	3.04	0.28
1.80	30.20	0.93	2.46	3.39	1.42	4.81	3.00	3.02	0.27
1.82	30.54	0.91	2.48	3.39	1.39	4.78	3.00	3.01	0.25
1.84	30.87	0.89	2.50	3.39	1.37	4.76	3.00	2.99	0.24
1.86	31.21	0.87	2.52	3.39	1.35	4.74	3.00	2.97	0.23
1.88	31.54	0.85	2.53	3.39	1.33	4.72	3.00	2.96	0.22
1.90	31.88	0.84	2.55	3.39	1.31	4.70	3.00	2.94	0.21
1.92	32.21	0.82	2.57	3.39	1.29	4.68	3.00	2.93	0.20
1.94	32.55	0.80	2.59	3.39	1.27	4.66	3.00	2.91	0.19
1.96	32.88	0.78	2.61	3.39	1.25	4.64	3.00	2.89	0.19
1.98	33.22	0.77	2.63	3.39	1.23	4.63	3.00	2.88	0.18

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, ACTIVATED SLUDGE AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	11.24	0.37	0.0	8.84	0.37	C.0
MINIMUM DO, MG/L	4.03	33.22	1.98	3.93	33.22	1.98
FINAL DO, MG/L	6.33	13.56	0.80	6.12	13.56	0.80
DO DEFICIT						
INITIAL, MG/L	2.38	0.37	0.0	4.78	0.37	0.0
FINAL, MG/L	7.88	13.56	0.80	8.09	13.56	0.80
RIVER DISCHARGE						
INITIAL, CFS	59.10	0.37	0.0	59.10	0.37	0.0
FINAL, CFS	60.42	13.56	0.80	60.42	13.56	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	34.77	0.37	0.0	34.77	0.37	0.0
FINAL, DEG F	32.03	13.56	0.80	32.03	13.56	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	7.63	0.37	0.0	7.63	0.37	0.0
FINAL BOD, MG/L	2.78	13.56	0.80	2.79	13.56	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.50	13.56	0.80	1.56	13.56	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	5.73	0.37	0.0	5.73	0.37	0.0
FINAL BOD, MG/L	3.04	13.56	0.80	3.04	13.56	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	14.04	0.37	0.0	14.20	0.37	0.0
FINAL VALUE, MG/L	7.33	13.56	0.80	7.40	13.56	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	4.19	0.37	0.0	4.19	0.37	0.0
FINAL VALUE, MG/L	2.23	13.56	0.80	2.23	13.56	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.31	0.37	0.0	3.31	0.37	0.0
FINAL VALUE, MG/L	3.00	13.56	0.80	3.00	13.56	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	4.96	0.37	0.0	4.96	0.37	0.0
FINAL VALUE, MG/L	3.97	13.56	0.80	3.97	13.56	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	15.49	0.37	0.0	15.49	0.37	0.0
FINAL PERCENT	2.49	13.56	0.80	2.49	13.56	0.80

K. Computer Results for 1990 Design Level, Activated Sludge, Ames Reservoir and Lagoon, Winter, 10 Yr, Low Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNF	NITRE	PO4E	COLIE			GAMA1	GAMA2
2.94	50.00	25.00	0.0	29.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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               AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
     SEASON : WINTER

 GAMMA1 =    0.80 , GAMMA2 =    0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS     40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS    1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =    4.55 CFS, RIVER Q =   50.00 CFS, TOTAL Q =  54.55 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =    0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		50.0	12.79	9.95		0.40
0.0	0.37	33.5	33.5	33.5	54.6	11.95	9.35	10.65	2.45
0.02	0.69	33.3	33.3	33.3	54.6	11.89	9.64	10.76	2.41
0.04	1.01	33.2	33.2	33.2	54.6	11.84	9.89	10.87	2.37
0.06	1.33	33.1	33.1	33.1	54.6	11.80	10.12	10.96	2.34
0.08	1.65	32.9	32.9	32.9	54.7	11.78	10.32	11.05	2.30
0.10	1.96	32.8	32.8	32.8	54.7	11.76	10.50	11.13	2.26
0.12	2.28	32.8	32.8	32.8	54.7	11.76	10.66	11.21	2.23
0.14	2.60	32.7	32.7	32.7	54.8	11.76	10.81	11.28	2.19
0.16	2.92	32.6	32.6	32.6	54.8	11.76	10.94	11.35	2.16
0.18	3.24	32.5	32.5	32.5	54.8	11.77	11.06	11.42	2.12
0.20	3.56	32.5	32.5	32.5	54.9	11.79	11.17	11.48	2.09
0.22	3.88	32.4	32.4	32.4	54.9	11.51	10.90	11.21	2.06
0.24	4.20	32.4	32.4	32.4	54.9	11.25	10.64	10.95	2.02
0.26	4.52	32.3	32.3	32.3	55.0	10.99	10.39	10.69	1.99
0.28	4.84	32.3	32.3	32.3	55.0	10.74	10.14	10.44	1.96
0.30	5.16	32.3	32.3	32.3	55.0	10.50	9.90	10.20	1.93
0.32	5.48	32.2	32.2	32.2	55.1	10.26	9.67	9.96	1.90
0.34	5.80	32.2	32.2	32.2	55.1	10.02	9.44	9.73	1.87
0.36	6.12	32.2	32.2	32.2	55.1	9.80	9.22	9.51	1.84
0.38	6.44	32.2	32.2	32.2	55.2	9.58	9.01	9.29	1.82
0.40	6.76	32.2	32.2	32.2	55.2	9.37	8.80	9.08	1.79
0.42	7.08	32.1	32.1	32.1	55.2	9.16	8.60	8.88	1.76
0.44	7.40	32.1	32.1	32.1	55.3	8.96	8.40	8.68	1.73
0.46	7.72	32.1	32.1	32.1	55.3	8.76	8.21	8.48	1.71
0.48	8.04	32.1	32.1	32.1	55.3	8.57	8.02	8.30	1.68
0.50	8.36	32.1	32.1	32.1	55.3	8.39	7.84	8.11	1.66

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.68	32.1	32.1	32.1	55.4	8.21	7.67	7.94	1.63
0.54	9.00	32.1	32.1	32.1	55.4	8.03	7.50	7.77	1.61
0.56	9.32	32.1	32.1	32.1	55.4	7.87	7.34	7.60	1.58
0.58	9.64	32.1	32.1	32.1	55.5	7.70	7.18	7.44	1.56
0.60	9.96	32.0	32.0	32.0	55.5	7.54	7.02	7.28	1.53
0.62	10.28	32.0	32.0	32.0	55.5	7.39	6.88	7.13	1.51
0.64	10.60	32.0	32.0	32.0	55.6	7.24	6.73	6.99	1.49
0.66	10.93	32.0	32.0	32.0	55.6	7.10	6.59	6.85	1.46
0.68	11.25	32.0	32.0	32.0	55.6	6.96	6.46	6.71	1.44
0.70	11.57	32.0	32.0	32.0	55.7	6.82	6.33	6.58	1.42
0.72	11.89	32.0	32.0	32.0	55.7	6.69	6.20	6.45	1.40
0.74	12.21	32.0	32.0	32.0	55.7	6.57	6.08	6.32	1.38
0.76	12.53	32.0	32.0	32.0	55.8	6.44	5.96	6.20	1.36
0.78	12.85	32.0	32.0	32.0	55.8	6.32	5.85	6.09	1.33
0.80	13.17	32.0	32.0	32.0	55.8	6.21	5.74	5.97	1.31
0.82	13.50	32.0	32.0	32.0	55.9	6.10	5.63	5.86	1.29
0.84	13.82	32.0	32.0	32.0	55.9	5.99	5.52	5.76	1.28
0.86	14.14	32.0	32.0	32.0	55.9	5.89	5.42	5.66	1.26
0.88	14.46	32.0	32.0	32.0	56.0	5.79	5.33	5.56	1.24
0.90	14.78	32.0	32.0	32.0	56.0	5.69	5.23	5.46	1.22
0.92	15.11	32.0	32.0	32.0	56.0	5.59	5.14	5.37	1.20
0.94	15.43	32.0	32.0	32.0	56.1	5.50	5.06	5.28	1.18
0.96	15.75	32.0	32.0	32.0	56.1	5.41	4.97	5.19	1.16
0.98	16.07	32.0	32.0	32.0	56.1	5.33	4.89	5.11	1.15
1.00	16.39	32.0	32.0	32.0	56.2	5.24	4.81	5.03	1.13
1.02	16.72	32.0	32.0	32.0	56.2	5.16	4.73	4.95	1.11

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	17.04	32.0	32.0	32.0	56.2	5.09	4.66	4.87	1.09
1.06	17.36	32.0	32.0	32.0	56.2	5.01	4.59	4.80	1.08
1.08	17.68	32.0	32.0	32.0	56.3	4.94	4.52	4.73	1.06
1.10	18.01	32.0	32.0	32.0	56.3	4.87	4.45	4.66	1.05
1.12	18.33	32.0	32.0	32.0	56.3	4.80	4.39	4.59	1.03
1.14	18.65	32.0	32.0	32.0	56.4	4.73	4.32	4.53	1.01
1.16	18.97	32.0	32.0	32.0	56.4	4.67	4.26	4.46	1.00
1.18	19.30	32.0	32.0	32.0	56.4	4.60	4.20	4.40	0.98
1.20	19.62	32.0	32.0	32.0	56.5	4.54	4.15	4.34	0.97
1.22	19.94	32.0	32.0	32.0	56.5	4.48	4.09	4.29	0.95
1.24	20.26	32.0	32.0	32.0	56.5	4.43	4.04	4.23	0.94
1.26	20.59	32.0	32.0	32.0	56.6	4.37	3.99	4.18	0.93
1.28	20.91	32.0	32.0	32.0	56.6	4.32	3.94	4.13	0.91
1.30	21.23	32.0	32.0	32.0	56.6	4.26	3.89	4.08	0.90
1.32	21.56	32.0	32.0	32.0	56.7	4.21	3.84	4.03	0.88
1.34	21.88	32.0	32.0	32.0	56.7	4.16	3.79	3.98	0.87
1.36	22.20	32.0	32.0	32.0	56.7	4.12	3.75	3.93	0.86
1.38	22.53	32.0	32.0	32.0	56.8	4.07	3.71	3.89	0.84
1.40	22.85	32.0	32.0	32.0	56.8	4.02	3.66	3.84	0.83
1.42	23.17	32.0	32.0	32.0	56.8	3.98	3.62	3.80	0.82
1.44	23.50	32.0	32.0	32.0	56.9	3.94	3.58	3.76	0.81
1.46	23.82	32.0	32.0	32.0	56.9	3.89	3.54	3.72	0.79
1.48	24.15	32.0	32.0	32.0	56.9	3.85	3.51	3.68	0.78
1.50	24.47	32.0	32.0	32.0	57.0	3.81	3.47	3.64	0.77
1.52	24.79	32.0	32.0	32.0	57.0	3.77	3.43	3.60	0.76
1.54	25.12	32.0	32.0	32.0	57.0	3.74	3.40	3.57	0.75

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	25.44	32.0	32.0	32.0	57.1	3.70	3.36	3.53	0.74
1.58	25.77	32.0	32.0	32.0	57.1	3.66	3.33	3.50	0.73
1.60	26.09	32.0	32.0	32.0	57.1	3.62	3.30	3.46	0.71
1.62	26.41	32.0	32.0	32.0	57.2	3.59	3.26	3.43	0.70
1.64	26.74	32.0	32.0	32.0	57.2	3.55	3.23	3.39	0.69
1.66	27.06	32.0	32.0	32.0	57.2	3.52	3.20	3.36	0.68
1.68	27.39	32.0	32.0	32.0	57.3	3.49	3.17	3.33	0.67
1.70	27.71	32.0	32.0	32.0	57.3	3.45	3.14	3.30	0.66
1.72	28.04	32.0	32.0	32.0	57.3	3.42	3.11	3.26	0.65
1.74	28.36	32.0	32.0	32.0	57.3	3.39	3.08	3.23	0.64
1.76	28.69	32.0	32.0	32.0	57.4	3.36	3.05	3.20	0.63
1.78	29.01	32.0	32.0	32.0	57.4	3.32	3.02	3.17	0.62
1.80	29.34	32.0	32.0	32.0	57.4	3.29	2.99	3.14	0.61
1.82	29.66	32.0	32.0	32.0	57.5	3.26	2.96	3.11	0.60
1.84	29.99	32.0	32.0	32.0	57.5	3.23	2.94	3.08	0.60
1.86	30.31	32.0	32.0	32.0	57.5	3.20	2.91	3.05	0.59
1.88	30.64	32.0	32.0	32.0	57.6	3.17	2.88	3.02	0.58
1.90	30.96	32.0	32.0	32.0	57.6	3.14	2.85	2.99	0.57
1.92	31.29	32.0	32.0	32.0	57.6	3.10	2.82	2.96	0.56
1.94	31.61	32.0	32.0	32.0	57.7	3.07	2.79	2.93	0.55
1.96	31.94	32.0	32.0	32.0	57.7	3.04	2.76	2.90	0.54
1.98	32.26	32.0	32.0	32.0	57.7	3.01	2.73	2.87	0.54

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.77	2.77	0.55	3.32	3.00	0.40	0.10
0.0	0.37	5.05	0.84	5.89	3.35	9.24	3.17	2.87	8.43
0.02	0.69	4.94	0.86	5.80	3.30	9.10	3.14	2.85	8.05
0.04	1.01	4.81	0.88	5.70	3.25	8.94	3.11	2.84	7.68
0.06	1.33	4.69	0.91	5.60	3.19	8.79	3.08	2.82	7.33
0.08	1.65	4.58	0.93	5.51	3.14	8.65	3.05	2.80	7.00
0.10	1.96	4.47	0.95	5.42	3.09	8.51	3.02	2.79	6.69
0.12	2.28	4.36	0.97	5.33	3.04	8.38	3.00	2.77	6.39
0.14	2.60	4.25	0.99	5.25	3.00	8.24	3.00	2.76	6.10
0.16	2.92	4.15	1.01	5.17	2.95	8.12	3.00	2.74	5.83
0.18	3.24	4.05	1.04	5.09	2.90	7.99	3.00	2.73	5.57
0.20	3.56	3.96	1.06	5.02	2.86	7.87	3.00	2.71	5.32
0.22	3.88	3.86	1.08	4.94	2.81	7.76	3.00	2.70	5.08
0.24	4.20	3.77	1.10	4.88	2.77	7.65	3.00	2.68	4.86
0.26	4.52	3.69	1.12	4.81	2.73	7.54	3.00	2.67	4.64
0.28	4.84	3.60	1.14	4.74	2.68	7.43	3.00	2.65	4.44
0.30	5.16	3.52	1.17	4.68	2.64	7.33	3.00	2.64	4.24
0.32	5.48	3.44	1.19	4.62	2.60	7.23	3.00	2.62	4.05
0.34	5.80	3.36	1.21	4.57	2.56	7.13	3.00	2.61	3.88
0.36	6.12	3.28	1.23	4.51	2.52	7.03	3.00	2.59	3.70
0.38	6.44	3.20	1.25	4.46	2.48	6.94	3.00	2.58	3.54
0.40	6.76	3.13	1.27	4.40	2.45	6.85	3.00	2.57	3.38
0.42	7.08	3.06	1.29	4.35	2.41	6.76	3.00	2.55	3.24
0.44	7.40	2.99	1.31	4.31	2.37	6.68	3.00	2.54	3.09
0.46	7.72	2.92	1.33	4.26	2.34	6.59	3.00	2.52	2.96
0.48	8.04	2.86	1.36	4.21	2.30	6.51	3.00	2.51	2.83
0.50	8.36	2.79	1.38	4.17	2.26	6.44	3.00	2.50	2.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.68	2.73	1.40	4.13	2.23	6.36	3.00	2.48	2.58
0.54	9.00	2.67	1.42	4.09	2.20	6.28	3.00	2.47	2.47
0.56	9.32	2.61	1.44	4.05	2.16	6.21	3.00	2.46	2.36
0.58	9.64	2.55	1.46	4.01	2.13	6.14	3.00	2.44	2.26
0.60	9.96	2.50	1.48	3.98	2.10	6.07	3.00	2.43	2.16
0.62	10.28	2.44	1.50	3.94	2.06	6.01	3.00	2.42	2.06
0.64	10.60	2.39	1.52	3.91	2.03	5.94	3.00	2.40	1.97
0.66	10.93	2.34	1.54	3.88	2.00	5.88	3.00	2.39	1.89
0.68	11.25	2.29	1.56	3.85	1.97	5.82	3.00	2.38	1.80
0.70	11.57	2.24	1.58	3.82	1.94	5.76	3.00	2.37	1.72
0.72	11.89	2.19	1.60	3.79	1.91	5.70	3.00	2.35	1.65
0.74	12.21	2.14	1.62	3.76	1.88	5.64	3.00	2.34	1.58
0.76	12.53	2.09	1.64	3.73	1.85	5.59	3.00	2.33	1.51
0.78	12.85	2.05	1.66	3.71	1.83	5.54	3.00	2.31	1.44
0.80	13.17	2.00	1.68	3.69	1.80	5.48	3.00	2.30	1.38
0.82	13.50	1.96	1.70	3.66	1.77	5.43	3.00	2.29	1.32
0.84	13.82	1.92	1.72	3.64	1.74	5.38	3.00	2.28	1.26
0.86	14.14	1.88	1.74	3.62	1.72	5.34	3.00	2.26	1.20
0.88	14.46	1.84	1.76	3.60	1.69	5.29	3.00	2.25	1.15
0.90	14.78	1.80	1.78	3.58	1.67	5.25	3.00	2.24	1.10
0.92	15.11	1.76	1.80	3.56	1.64	5.20	3.00	2.23	1.05
0.94	15.43	1.72	1.82	3.54	1.62	5.16	3.00	2.22	1.01
0.96	15.75	1.68	1.84	3.53	1.59	5.12	3.00	2.20	0.96
0.98	16.07	1.65	1.86	3.51	1.57	5.08	3.00	2.19	0.92
1.00	16.39	1.61	1.88	3.50	1.54	5.04	3.00	2.18	0.88
1.02	16.72	1.58	1.90	3.48	1.52	5.00	3.00	2.17	0.84

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	17.04	1.55	1.92	3.47	1.50	4.96	3.00	2.16	0.80
1.06	17.36	1.51	1.94	3.45	1.47	4.93	3.00	2.15	0.77
1.08	17.68	1.48	1.96	3.44	1.45	4.89	3.00	2.13	0.74
1.10	18.01	1.45	1.98	3.43	1.43	4.86	3.00	2.12	0.70
1.12	18.33	1.42	2.00	3.42	1.41	4.83	3.00	2.11	0.67
1.14	18.65	1.39	2.02	3.41	1.39	4.80	3.00	2.10	0.64
1.16	18.97	1.36	2.04	3.40	1.37	4.77	3.00	2.09	0.61
1.18	19.30	1.33	2.06	3.39	1.35	4.74	3.00	2.08	0.59
1.20	19.62	1.31	2.08	3.38	1.32	4.71	3.00	2.07	0.56
1.22	19.94	1.28	2.10	3.38	1.30	4.68	3.00	2.05	0.54
1.24	20.26	1.25	2.12	3.37	1.28	4.65	3.00	2.04	0.51
1.26	20.59	1.23	2.14	3.36	1.27	4.63	3.00	2.03	0.49
1.28	20.91	1.20	2.16	3.36	1.25	4.60	3.00	2.02	0.47
1.30	21.23	1.18	2.17	3.35	1.23	4.58	3.00	2.01	0.45
1.32	21.56	1.15	2.19	3.35	1.21	4.55	3.00	2.00	0.43
1.34	21.88	1.13	2.21	3.34	1.19	4.53	3.00	1.99	0.41
1.36	22.20	1.10	2.23	3.34	1.17	4.51	3.00	1.98	0.39
1.38	22.53	1.08	2.25	3.33	1.16	4.49	3.00	1.97	0.38
1.40	22.85	1.06	2.27	3.33	1.14	4.47	3.00	1.96	0.36
1.42	23.17	1.04	2.29	3.33	1.12	4.45	3.00	1.95	0.34
1.44	23.50	1.02	2.31	3.33	1.10	4.43	3.00	1.94	0.33
1.46	23.82	0.99	2.33	3.32	1.09	4.41	3.00	1.93	0.31
1.48	24.15	0.97	2.35	3.32	1.07	4.39	3.00	1.92	0.30
1.50	24.47	0.95	2.37	3.32	1.05	4.38	3.00	1.90	0.29
1.52	24.79	0.93	2.39	3.32	1.04	4.36	3.00	1.89	0.27
1.54	25.12	0.92	2.40	3.32	1.02	4.34	3.00	1.88	0.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

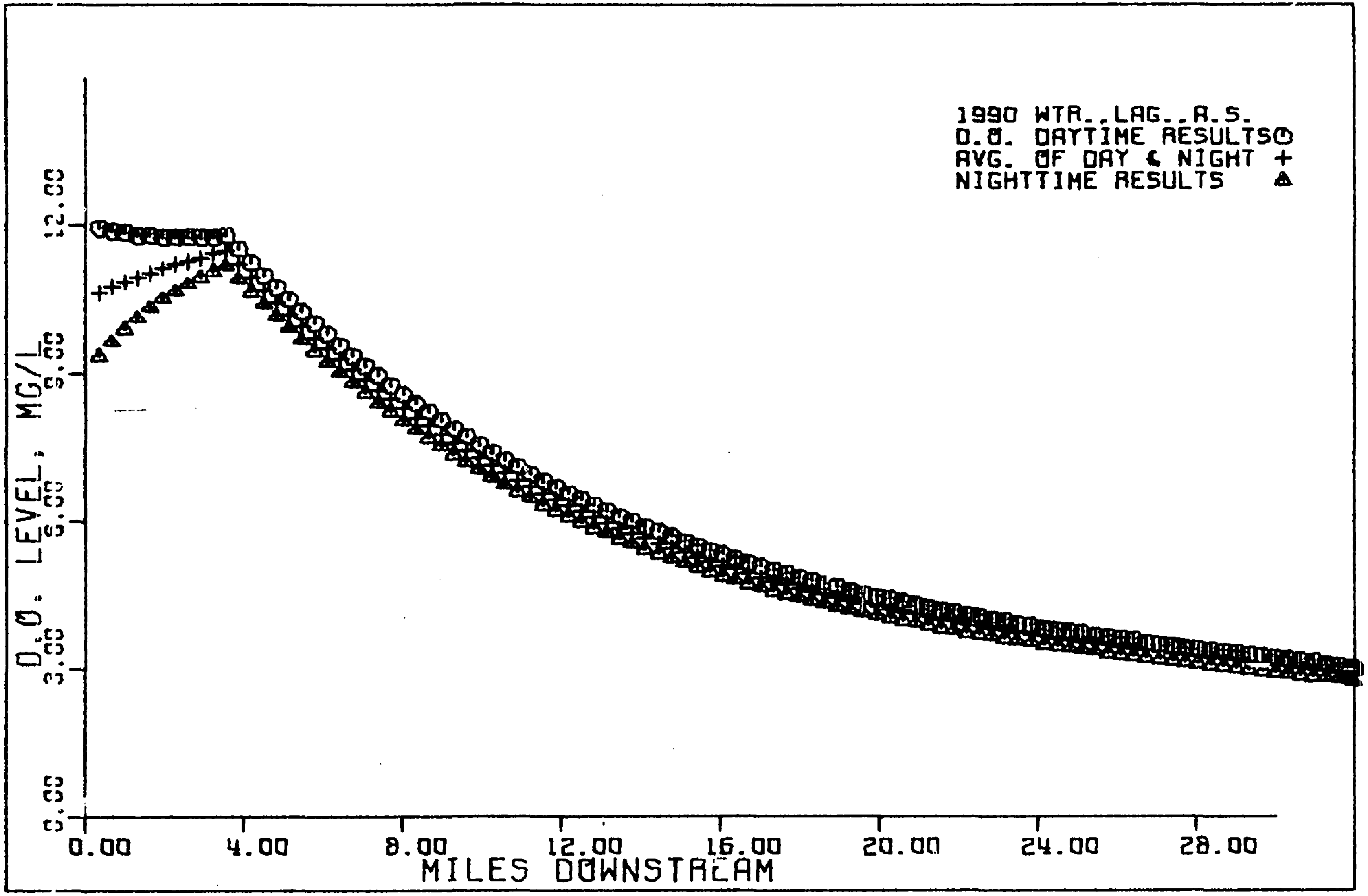
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	25.44	0.90	2.42	3.32	1.01	4.33	3.00	1.87	0.25
1.58	25.77	0.88	2.44	3.32	0.99	4.31	3.00	1.86	0.24
1.60	26.09	0.86	2.46	3.32	0.98	4.30	3.00	1.85	0.23
1.62	26.41	0.84	2.48	3.32	0.96	4.29	3.00	1.84	0.22
1.64	26.74	0.83	2.50	3.32	0.95	4.27	3.00	1.83	0.21
1.66	27.06	0.81	2.52	3.33	0.93	4.26	3.00	1.82	0.20
1.68	27.39	0.79	2.54	3.33	0.92	4.25	3.00	1.81	0.19
1.70	27.71	0.78	2.56	3.33	0.91	4.24	3.00	1.80	0.18
1.72	28.04	0.76	2.57	3.33	0.89	4.23	3.00	1.80	0.18
1.74	28.36	0.75	2.59	3.34	0.88	4.22	3.00	1.79	0.17
1.76	28.69	0.73	2.61	3.34	0.87	4.21	3.00	1.78	0.16
1.78	29.01	0.72	2.63	3.34	0.85	4.20	3.00	1.77	0.15
1.80	29.34	0.70	2.65	3.35	0.84	4.19	3.00	1.76	0.15
1.82	29.66	0.69	2.67	3.35	0.83	4.18	3.00	1.75	0.14
1.84	29.99	0.67	2.69	3.36	0.82	4.17	3.00	1.74	0.13
1.86	30.31	0.66	2.70	3.36	0.80	4.17	3.00	1.73	0.13
1.88	30.64	0.65	2.72	3.37	0.79	4.16	3.00	1.72	0.12
1.90	30.96	0.63	2.74	3.37	0.78	4.15	3.00	1.71	0.12
1.92	31.29	0.62	2.76	3.38	0.77	4.15	3.00	1.70	0.11
1.94	31.61	0.61	2.78	3.38	0.76	4.14	3.00	1.69	0.11
1.96	31.94	0.59	2.80	3.39	0.74	4.13	3.00	1.68	0.10
1.98	32.26	0.58	2.81	3.40	0.73	4.13	3.00	1.67	0.10

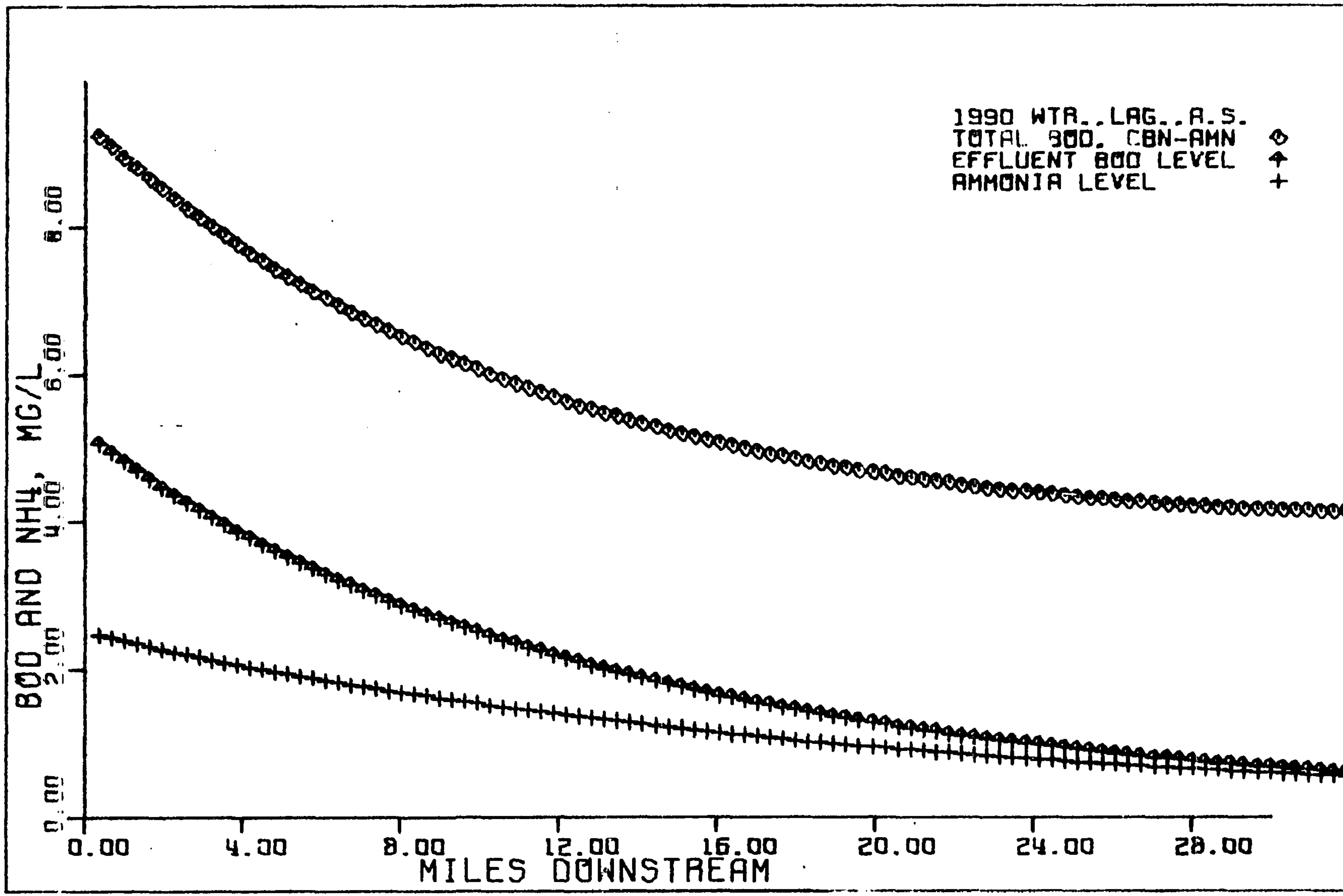
WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	11.95	0.37	0.0	9.35	0.37	0.0
MINIMUM DO, MG/L	3.01	32.26	1.98	2.73	32.26	1.98
FINAL DO, MG/L	6.21	13.17	0.80	5.74	13.17	0.80
DO DEFICIT						
INITIAL, MG/L	1.93	0.37	0.0	4.54	0.37	0.0
FINAL, MG/L	8.00	13.17	0.80	8.47	13.17	0.80
RIVER DISCHARGE						
INITIAL, CFS	54.55	0.37	0.0	54.55	0.37	0.0
FINAL, CFS	55.83	13.17	0.80	55.83	13.17	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	33.50	0.37	0.0	33.50	0.37	0.0
FINAL, DEG F	32.02	13.17	0.80	32.02	13.17	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	5.05	0.37	0.0	5.05	0.37	0.0
FINAL BOD, MG/L	2.00	13.17	0.80	2.00	13.17	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.66	13.17	0.80	1.71	13.17	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	3.35	0.37	0.0	3.35	0.37	0.0
FINAL BOD, MG/L	1.80	13.17	0.80	1.80	13.17	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	9.18	0.37	0.0	9.31	0.37	0.0
FINAL VALUE, MG/L	5.46	13.17	0.80	5.51	13.17	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	2.45	0.37	0.0	2.45	0.37	0.0
FINAL VALUE, MG/L	1.31	13.17	0.80	1.31	13.17	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.17	0.37	0.0	3.17	0.37	0.0
FINAL VALUE, MG/L	3.00	13.17	0.80	3.00	13.17	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	2.87	0.37	0.0	2.87	0.37	0.0
FINAL VALUE, MG/L	2.30	13.17	0.80	2.30	13.17	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	8.43	0.37	0.0	8.43	0.37	0.0
FINAL PERCENT	1.38	13.17	0.80	1.38	13.17	0.80


1990 WTR..LAG..A.S.
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM


1990 WTR..LAG..A.S.
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
2.00
4.00
6.00
8.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM

L. Computer Results for 1990 Design Level, Activated Sludge, Ames Reservoir and Lagoon, Winter, 10 Yr, High Reaeration Coefficient

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION   IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
2.94	50.00	25.00	0.0	29.00	0.080	0.0	25.00	5.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
50.00	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2P
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.300	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

GAMMA1 = 0.80 , GAMMA2 = 0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES

IF PROGRAM IS CYCLING, THIS RUN IS FOR:
CYCLE NO. 1
BANK LOAD IS 40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR 0.0 LBS/DAY/MILE
ADDITIONAL BANK LOAD DOWNSTREAM IS 1.00 LBS/DAY/MILE
FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS: 4.00 MG/L
EFFLUENT Q = 4.55 CFS, RIVER Q = 50.00 CFS, TOTAL Q = 54.55 CFS
CYCLE INCREMENT IS 0.0 CFS
FOR ALGAE VARIATIONS, P-MINUS-R = 0.80 MG/L/HR
CYCLE INCREMENT IS 0.0 MG/L/HR

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		50.0	12.79	9.95		0.40
0.0	0.37	33.5	33.5	33.5	54.6	11.95	9.35	10.65	2.45
0.02	0.69	33.3	33.3	33.3	54.6	11.89	9.64	10.76	2.41
0.04	1.01	33.2	33.2	33.2	54.6	11.84	9.89	10.87	2.37
0.06	1.33	33.1	33.1	33.1	54.6	11.80	10.12	10.96	2.34
0.08	1.65	32.9	32.9	32.9	54.7	11.78	10.32	11.05	2.30
0.10	1.96	32.8	32.8	32.8	54.7	11.76	10.50	11.13	2.26
0.12	2.28	32.8	32.8	32.8	54.7	11.76	10.66	11.21	2.23
0.14	2.60	32.7	32.7	32.7	54.8	11.76	10.81	11.28	2.19
0.16	2.92	32.6	32.6	32.6	54.8	11.76	10.94	11.35	2.16
0.18	3.24	32.5	32.5	32.5	54.8	11.77	11.06	11.42	2.12
0.20	3.56	32.5	32.5	32.5	54.9	11.79	11.17	11.48	2.09
0.22	3.88	32.4	32.4	32.4	54.9	11.52	10.92	11.22	2.06
0.24	4.20	32.4	32.4	32.4	54.9	11.27	10.67	10.97	2.02
0.26	4.52	32.3	32.3	32.3	55.0	11.03	10.43	10.73	1.99
0.28	4.84	32.3	32.3	32.3	55.0	10.79	10.20	10.50	1.96
0.30	5.16	32.3	32.3	32.3	55.0	10.56	9.98	10.27	1.93
0.32	5.48	32.2	32.2	32.2	55.1	10.34	9.77	10.05	1.90
0.34	5.80	32.2	32.2	32.2	55.1	10.12	9.56	9.84	1.87
0.36	6.12	32.2	32.2	32.2	55.1	9.91	9.36	9.64	1.84
0.38	6.44	32.2	32.2	32.2	55.2	9.71	9.16	9.44	1.82
0.40	6.76	32.2	32.2	32.2	55.2	9.52	8.98	9.25	1.79
0.42	7.08	32.1	32.1	32.1	55.2	9.33	8.80	9.06	1.76
0.44	7.40	32.1	32.1	32.1	55.3	9.15	8.62	8.89	1.73
0.46	7.72	32.1	32.1	32.1	55.3	8.97	8.45	8.71	1.71
0.48	8.04	32.1	32.1	32.1	55.3	8.81	8.29	8.55	1.68
0.50	8.36	32.1	32.1	32.1	55.3	8.64	8.14	8.39	1.66

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	8.68	32.1	32.1	32.1	55.4	8.49	7.99	8.24	1.63
0.54	9.00	32.1	32.1	32.1	55.4	8.34	7.85	8.09	1.61
0.56	9.32	32.1	32.1	32.1	55.4	8.19	7.71	7.95	1.58
0.58	9.64	32.1	32.1	32.1	55.5	8.06	7.58	7.82	1.56
0.60	9.96	32.0	32.0	32.0	55.5	7.92	7.45	7.69	1.53
0.62	10.28	32.0	32.0	32.0	55.5	7.79	7.33	7.56	1.51
0.64	10.60	32.0	32.0	32.0	55.6	7.67	7.21	7.44	1.49
0.66	10.93	32.0	32.0	32.0	55.6	7.55	7.10	7.33	1.46
0.68	11.25	32.0	32.0	32.0	55.6	7.44	6.99	7.21	1.44
0.70	11.57	32.0	32.0	32.0	55.7	7.33	6.89	7.11	1.42
0.72	11.89	32.0	32.0	32.0	55.7	7.23	6.79	7.01	1.40
0.74	12.21	32.0	32.0	32.0	55.7	7.13	6.70	6.91	1.38
0.76	12.53	32.0	32.0	32.0	55.8	7.03	6.61	6.82	1.36
0.78	12.85	32.0	32.0	32.0	55.8	6.94	6.52	6.73	1.33
0.80	13.17	32.0	32.0	32.0	55.8	6.85	6.44	6.65	1.31
0.82	13.50	32.0	32.0	32.0	55.9	6.77	6.36	6.56	1.29
0.84	13.82	32.0	32.0	32.0	55.9	6.69	6.29	6.49	1.28
0.86	14.14	32.0	32.0	32.0	55.9	6.61	6.21	6.41	1.26
0.88	14.46	32.0	32.0	32.0	56.0	6.54	6.15	6.34	1.24
0.90	14.78	32.0	32.0	32.0	56.0	6.47	6.08	6.28	1.22
0.92	15.11	32.0	32.0	32.0	56.0	6.40	6.02	6.21	1.20
0.94	15.43	32.0	32.0	32.0	56.1	6.34	5.96	6.15	1.18
0.96	15.75	32.0	32.0	32.0	56.1	6.28	5.91	6.09	1.16
0.98	16.07	32.0	32.0	32.0	56.1	6.22	5.85	6.04	1.15
1.00	16.39	32.0	32.0	32.0	56.2	6.17	5.80	5.98	1.13
1.02	16.72	32.0	32.0	32.0	56.2	6.11	5.76	5.93	1.11

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	17.04	32.0	32.0	32.0	56.2	6.06	5.71	5.89	1.09
1.06	17.36	32.0	32.0	32.0	56.2	6.01	5.67	5.84	1.08
1.08	17.68	32.0	32.0	32.0	56.3	5.97	5.63	5.80	1.06
1.10	18.01	32.0	32.0	32.0	56.3	5.93	5.59	5.76	1.05
1.12	18.33	32.0	32.0	32.0	56.3	5.89	5.55	5.72	1.03
1.14	18.65	32.0	32.0	32.0	56.4	5.85	5.52	5.68	1.01
1.16	18.97	32.0	32.0	32.0	56.4	5.81	5.49	5.65	1.00
1.18	19.30	32.0	32.0	32.0	56.4	5.77	5.45	5.61	0.98
1.20	19.62	32.0	32.0	32.0	56.5	5.74	5.43	5.58	0.97
1.22	19.94	32.0	32.0	32.0	56.5	5.71	5.40	5.55	0.95
1.24	20.26	32.0	32.0	32.0	56.5	5.68	5.37	5.53	0.94
1.26	20.59	32.0	32.0	32.0	56.6	5.65	5.35	5.50	0.93
1.28	20.91	32.0	32.0	32.0	56.6	5.62	5.33	5.47	0.91
1.30	21.23	32.0	32.0	32.0	56.6	5.60	5.30	5.45	0.90
1.32	21.56	32.0	32.0	32.0	56.7	5.57	5.28	5.43	0.88
1.34	21.38	32.0	32.0	32.0	56.7	5.55	5.26	5.41	0.87
1.36	22.20	32.0	32.0	32.0	56.7	5.53	5.25	5.39	0.86
1.38	22.53	32.0	32.0	32.0	56.8	5.51	5.23	5.37	0.84
1.40	22.85	32.0	32.0	32.0	56.8	5.49	5.21	5.35	0.83
1.42	23.17	32.0	32.0	32.0	56.8	5.47	5.20	5.33	0.82
1.44	23.50	32.0	32.0	32.0	56.9	5.45	5.19	5.32	0.81
1.46	23.82	32.0	32.0	32.0	56.9	5.44	5.17	5.30	0.79
1.48	24.15	32.0	32.0	32.0	56.9	5.42	5.16	5.29	0.78
1.50	24.47	32.0	32.0	32.0	57.0	5.41	5.15	5.28	0.77
1.52	24.79	32.0	32.0	32.0	57.0	5.39	5.14	5.26	0.76
1.54	25.12	32.0	32.0	32.0	57.0	5.38	5.13	5.25	0.75

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	25.44	32.0	32.0	32.0	57.1	5.36	5.12	5.24	0.74
1.58	25.77	32.0	32.0	32.0	57.1	5.35	5.11	5.23	0.73
1.60	26.09	32.0	32.0	32.0	57.1	5.34	5.10	5.22	0.71
1.62	26.41	32.0	32.0	32.0	57.2	5.33	5.09	5.21	0.70
1.64	26.74	32.0	32.0	32.0	57.2	5.32	5.08	5.20	0.69
1.66	27.06	32.0	32.0	32.0	57.2	5.31	5.08	5.19	0.68
1.68	27.39	32.0	32.0	32.0	57.3	5.30	5.07	5.18	0.67
1.70	27.71	32.0	32.0	32.0	57.3	5.29	5.06	5.17	0.66
1.72	28.04	32.0	32.0	32.0	57.3	5.28	5.06	5.17	0.65
1.74	28.36	32.0	32.0	32.0	57.3	5.27	5.05	5.16	0.64
1.76	28.69	32.0	32.0	32.0	57.4	5.26	5.04	5.15	0.63
1.78	29.01	32.0	32.0	32.0	57.4	5.25	5.04	5.14	0.62
1.80	29.34	32.0	32.0	32.0	57.4	5.24	5.03	5.13	0.61
1.82	29.66	32.0	32.0	32.0	57.5	5.23	5.02	5.13	0.60
1.84	29.99	32.0	32.0	32.0	57.5	5.22	5.02	5.12	0.60
1.86	30.31	32.0	32.0	32.0	57.5	5.21	5.01	5.11	0.59
1.88	30.64	32.0	32.0	32.0	57.6	5.20	5.00	5.10	0.58
1.90	30.96	32.0	32.0	32.0	57.6	5.19	5.00	5.09	0.57
1.92	31.29	32.0	32.0	32.0	57.6	5.18	4.99	5.09	0.56
1.94	31.61	32.0	32.0	32.0	57.7	5.17	4.98	5.08	0.55
1.96	31.94	32.0	32.0	32.0	57.7	5.16	4.98	5.07	0.54
1.98	32.26	32.0	32.0	32.0	57.7	5.15	4.97	5.06	0.54

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.77	2.77	0.55	3.32	3.00	0.40	0.10
0.0	0.37	5.05	0.84	5.89	3.35	9.24	3.17	2.87	8.43
0.02	0.69	4.94	0.86	5.80	3.30	9.10	3.14	2.85	8.05
0.04	1.01	4.81	0.88	5.70	3.25	8.94	3.11	2.84	7.68
0.06	1.33	4.69	0.91	5.60	3.19	8.79	3.08	2.82	7.33
0.08	1.65	4.58	0.93	5.51	3.14	8.65	3.05	2.80	7.00
0.10	1.96	4.47	0.95	5.42	3.09	8.51	3.02	2.79	6.69
0.12	2.28	4.36	0.97	5.33	3.04	8.38	3.00	2.77	6.39
0.14	2.60	4.25	0.99	5.25	3.00	8.24	3.00	2.76	6.10
0.16	2.92	4.15	1.01	5.17	2.95	8.12	3.00	2.74	5.83
0.18	3.24	4.05	1.04	5.09	2.90	7.99	3.00	2.73	5.57
0.20	3.56	3.96	1.06	5.02	2.86	7.87	3.00	2.71	5.32
0.22	3.88	3.86	1.08	4.94	2.81	7.76	3.00	2.70	5.08
0.24	4.20	3.77	1.10	4.88	2.77	7.65	3.00	2.68	4.86
0.26	4.52	3.69	1.12	4.81	2.73	7.54	3.00	2.67	4.64
0.28	4.84	3.60	1.14	4.74	2.68	7.43	3.00	2.65	4.44
0.30	5.16	3.52	1.17	4.68	2.64	7.33	3.00	2.64	4.24
0.32	5.48	3.44	1.19	4.62	2.60	7.23	3.00	2.62	4.05
0.34	5.80	3.36	1.21	4.57	2.56	7.13	3.00	2.61	3.88
0.36	6.12	3.28	1.23	4.51	2.52	7.03	3.00	2.59	3.70
0.38	6.44	3.20	1.25	4.46	2.48	6.94	3.00	2.58	3.54
0.40	6.76	3.13	1.27	4.40	2.45	6.85	3.00	2.57	3.38
0.42	7.08	3.06	1.29	4.35	2.41	6.76	3.00	2.55	3.24
0.44	7.40	2.99	1.31	4.31	2.37	6.68	3.00	2.54	3.09
0.46	7.72	2.92	1.33	4.26	2.34	6.59	3.00	2.52	2.96
0.48	8.04	2.86	1.36	4.21	2.30	6.51	3.00	2.51	2.83
0.50	8.36	2.79	1.38	4.17	2.26	6.44	3.00	2.50	2.70

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	8.68	2.73	1.40	4.13	2.23	6.36	3.00	2.48	2.58
0.54	9.00	2.67	1.42	4.09	2.20	6.28	3.00	2.47	2.47
0.56	9.32	2.61	1.44	4.05	2.16	6.21	3.00	2.46	2.36
0.58	9.64	2.55	1.46	4.01	2.13	6.14	3.00	2.44	2.26
0.60	9.96	2.50	1.48	3.98	2.10	6.07	3.00	2.43	2.16
0.62	10.28	2.44	1.50	3.94	2.06	6.01	3.00	2.42	2.06
0.64	10.60	2.39	1.52	3.91	2.03	5.94	3.00	2.40	1.97
0.66	10.93	2.34	1.54	3.88	2.00	5.88	3.00	2.39	1.89
0.68	11.25	2.29	1.56	3.85	1.97	5.82	3.00	2.38	1.80
0.70	11.57	2.24	1.58	3.82	1.94	5.76	3.00	2.37	1.72
0.72	11.89	2.19	1.60	3.79	1.91	5.70	3.00	2.35	1.65
0.74	12.21	2.14	1.62	3.76	1.88	5.64	3.00	2.34	1.58
0.76	12.53	2.09	1.64	3.73	1.85	5.59	3.00	2.33	1.51
0.78	12.85	2.05	1.66	3.71	1.83	5.54	3.00	2.31	1.44
0.80	13.17	2.00	1.68	3.69	1.80	5.48	3.00	2.30	1.38
0.82	13.50	1.96	1.70	3.66	1.77	5.43	3.00	2.29	1.32
0.84	13.82	1.92	1.72	3.64	1.74	5.38	3.00	2.28	1.26
0.86	14.14	1.88	1.74	3.62	1.72	5.34	3.00	2.26	1.20
0.88	14.46	1.84	1.76	3.60	1.69	5.29	3.00	2.25	1.15
0.90	14.78	1.80	1.78	3.58	1.67	5.25	3.00	2.24	1.10
0.92	15.11	1.76	1.80	3.56	1.64	5.20	3.00	2.23	1.05
0.94	15.43	1.72	1.82	3.54	1.62	5.16	3.00	2.22	1.01
0.96	15.75	1.68	1.84	3.53	1.59	5.12	3.00	2.20	0.96
0.98	16.07	1.65	1.86	3.51	1.57	5.08	3.00	2.19	0.92
1.00	16.39	1.61	1.88	3.50	1.54	5.04	3.00	2.18	0.88
1.02	16.72	1.58	1.90	3.48	1.52	5.00	3.00	2.17	0.84

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	17.04	1.55	1.92	3.47	1.50	4.96	3.00	2.16	0.80
1.06	17.36	1.51	1.94	3.45	1.47	4.93	3.00	2.15	0.77
1.08	17.68	1.48	1.96	3.44	1.45	4.89	3.00	2.13	0.74
1.10	18.01	1.45	1.98	3.43	1.43	4.86	3.00	2.12	0.70
1.12	18.33	1.42	2.00	3.42	1.41	4.83	3.00	2.11	0.67
1.14	18.65	1.39	2.02	3.41	1.39	4.80	3.00	2.10	0.64
1.16	18.97	1.36	2.04	3.40	1.37	4.77	3.00	2.09	0.61
1.18	19.30	1.33	2.06	3.39	1.35	4.74	3.00	2.08	0.59
1.20	19.62	1.31	2.08	3.38	1.32	4.71	3.00	2.07	0.56
1.22	19.94	1.28	2.10	3.38	1.30	4.68	3.00	2.05	0.54
1.24	20.26	1.25	2.12	3.37	1.28	4.65	3.00	2.04	0.51
1.26	20.59	1.23	2.14	3.36	1.27	4.63	3.00	2.03	0.49
1.28	20.91	1.20	2.16	3.36	1.25	4.60	3.00	2.02	0.47
1.30	21.23	1.18	2.17	3.35	1.23	4.58	3.00	2.01	0.45
1.32	21.56	1.15	2.19	3.35	1.21	4.55	3.00	2.00	0.43
1.34	21.88	1.13	2.21	3.34	1.19	4.53	3.00	1.99	0.41
1.36	22.20	1.10	2.23	3.34	1.17	4.51	3.00	1.98	0.39
1.38	22.53	1.08	2.25	3.33	1.16	4.49	3.00	1.97	0.38
1.40	22.85	1.06	2.27	3.33	1.14	4.47	3.00	1.96	0.36
1.42	23.17	1.04	2.29	3.33	1.12	4.45	3.00	1.95	0.34
1.44	23.50	1.02	2.31	3.33	1.10	4.43	3.00	1.94	0.33
1.46	23.82	0.99	2.33	3.32	1.09	4.41	3.00	1.93	0.31
1.48	24.15	0.97	2.35	3.32	1.07	4.39	3.00	1.92	0.30
1.50	24.47	0.95	2.37	3.32	1.05	4.38	3.00	1.90	0.29
1.52	24.79	0.93	2.39	3.32	1.04	4.36	3.00	1.89	0.27
1.54	25.12	0.92	2.40	3.32	1.02	4.34	3.00	1.88	0.26

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	25.44	0.90	2.42	3.32	1.01	4.33	3.00	1.87	0.25
1.58	25.77	0.88	2.44	3.32	0.99	4.31	3.00	1.86	0.24
1.60	26.09	0.86	2.46	3.32	0.98	4.30	3.00	1.85	0.23
1.62	26.41	0.84	2.48	3.32	0.96	4.29	3.00	1.84	0.22
1.64	26.74	0.83	2.50	3.32	0.95	4.27	3.00	1.83	0.21
1.66	27.06	0.81	2.52	3.33	0.93	4.26	3.00	1.82	0.20
1.68	27.39	0.79	2.54	3.33	0.92	4.25	3.00	1.81	0.19
1.70	27.71	0.78	2.56	3.33	0.91	4.24	3.00	1.80	0.18
1.72	28.04	0.76	2.57	3.33	0.89	4.23	3.00	1.80	0.18
1.74	28.36	0.75	2.59	3.34	0.88	4.22	3.00	1.79	0.17
1.76	28.69	0.73	2.61	3.34	0.87	4.21	3.00	1.78	0.16
1.78	29.01	0.72	2.63	3.34	0.85	4.20	3.00	1.77	0.15
1.80	29.34	0.70	2.65	3.35	0.84	4.19	3.00	1.76	0.15
1.82	29.66	0.69	2.67	3.35	0.83	4.18	3.00	1.75	0.14
1.84	29.99	0.67	2.69	3.36	0.82	4.17	3.00	1.74	0.13
1.86	30.31	0.66	2.70	3.36	0.80	4.17	3.00	1.73	0.13
1.88	30.64	0.65	2.72	3.37	0.79	4.16	3.00	1.72	0.12
1.90	30.96	0.63	2.74	3.37	0.78	4.15	3.00	1.71	0.12
1.92	31.29	0.62	2.76	3.38	0.77	4.15	3.00	1.70	0.11
1.94	31.61	0.61	2.78	3.38	0.76	4.14	3.00	1.69	0.11
1.96	31.94	0.59	2.80	3.39	0.74	4.13	3.00	1.68	0.10
1.98	32.26	0.58	2.81	3.40	0.73	4.13	3.00	1.67	0.10

WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, A.S., LAGOON AND AMES RES.,10-YR.
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	11.95	0.37	0.0	9.35	0.37	0.0
MINIMUM DO, MG/L	5.15	32.26	1.98	4.97	32.26	1.98
FINAL DO, MG/L	6.85	13.17	0.80	6.44	13.17	0.80
DO DEFICIT						
INITIAL, MG/L	1.93	0.37	0.0	4.54	0.37	0.0
FINAL, MG/L	7.36	13.17	0.80	7.77	13.17	0.80
RIVER DISCHARGE						
INITIAL, CFS	54.55	0.37	0.0	54.55	0.37	0.0
FINAL, CFS	55.83	13.17	0.80	55.83	13.17	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	33.50	0.37	0.0	33.50	0.37	0.0
FINAL, DEG F	32.02	13.17	0.80	32.02	13.17	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	5.05	0.37	0.0	5.05	0.37	0.0
FINAL BOD, MG/L	2.00	13.17	0.80	2.00	13.17	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.04	0.37	0.0	0.04	0.37	0.0
FINAL BOD IN RIVER	1.66	13.17	0.80	1.71	13.17	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	3.35	0.37	0.0	3.35	0.37	0.0
FINAL BOD, MG/L	1.80	13.17	0.80	1.80	13.17	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	9.18	0.37	0.0	9.31	0.37	0.0
FINAL VALUE, MG/L	5.46	13.17	0.80	5.51	13.17	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	2.45	0.37	0.0	2.45	0.37	0.0
FINAL VALUE, MG/L	1.31	13.17	0.80	1.31	13.17	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.17	0.37	0.0	3.17	0.37	0.0
FINAL VALUE, MG/L	3.00	13.17	0.80	3.00	13.17	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	2.87	0.37	0.0	2.87	0.37	0.0
FINAL VALUE, MG/L	2.30	13.17	0.80	2.30	13.17	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	8.43	0.37	0.0	8.43	0.37	0.0
FINAL PERCENT	1.38	13.17	0.80	1.38	13.17	0.80

M. Computer Results for 1990 Design Level, Trickling Filter and Increased Low-Flow Augmentation, Winter, 10 Yr, Low Reaeration Coefficient

AMES WATER QUALITY MODEL

SANITARY ENGINEERING SECTION IOWA STATE UNIVERSITY

INPUT DATA FOR THIS ANALYSIS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

EFFLUENT DATA

QEMGD	TEMPE	PCSE		BODE	KDE	LAE	AMNE	NITRE	PO4E	COLIE			GAMA1	GAMA2
5.88	50.00	75.00	0.0	44.00	0.080	0.0	20.00	10.00	30.00	100.00	0.0	0.0	0.80	0.60

RIVER WATER QUALITY DATA

TMPRD	TMPRN	PCSRD	PCSRN	BODR	KDRLB	LAR	AMNR	NITRR	PO4R	COLIR	BLX	DBLX	ALPHA	BETA
32.00	32.00	90.00	70.00	2.00	0.140	0.0	0.40	3.00	0.40	0.10	40.00	1.00	0.25	0.50

RIVER DISCHARGE-VELOCITY DATA

QRCFS	DELQX	PSDQD	PSDQN	CVA	CVB	XIN	TIMIN	TIMFN	DTIM	KCOLI	KPOR	KNTR	KNR	KDR
100.00	0.10	50.00	50.00	0.149	0.374	0.37	0.0	2.00	0.02	2.500	0.500	1.500	1.500	0.0

ALGAE AND AIR TEMPERATURE FACTORS

TPBRD	TPBRN	KCTBR	TMPAD	TMPAN	CAALG	CBALG	TAUTM	PMR	PRRIN	PRRMX	BODDQ	DOFSH	K2ICE	K2R
32.00	32.00	2.500	0.0	0.0	3.000	0.100	0.40	0.80	1.40	2.00	0.50	4.00	0.200	0.0

MISCELLANEOUS CONTROL DATA

IBLCY	DBLCY	IDQCY	DLQCY	ILGCY	DPMR	IWTRA	IPNCH	IWRIT	IPLOT	NLIN
0	0.0	0	0.0	0	0.0	3	0	0	0	26

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            AMES WATER QUALITY MODEL
SANITARY ENGINEERING SECTION    IOWA STATE UNIVERSITY

     INPUT DATA FOR THIS ANALYSIS

     STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
     RUN IDENT : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
     SEASON : WINTER

 GAMMA1 =   0.80 , GAMMA2 =   0.60
ANALYSIS IS FOR ULTIMATE BOD VALUES IF GAMMA1 AND GAMMA2 = 1.0,
    OTHERWISE ANALYSIS IS FOR SIMULATED 5-DAY VALUES


IF PROGRAM IS CYCLING, THIS RUN IS FOR:
    CYCLE NO.  1
    BANK LOAD IS    40.00 LBS/DAY/MILE AT FIRST STA., CYCLE FOR   0.0 LBS/DAY/MILE
         ADDITIONAL BANK LOAD DOWNSTREAM IS   1.00 LBS/DAY/MILE
    FOR LOW FLOW AUGMENTATION, MIN. DO FOR FISH IS:  4.00 MG/L
         EFFLUENT Q =   9.10 CFS, RIVER Q = 100.00 CFS, TOTAL Q = 109.10 CFS
         CYCLE INCREMENT IS  0.0  CFS
    FOR ALGAE VARIATIONS, P-MINUS-R =   0.80 MG/L/HR
         CYCLE INCREMENT IS  0.0  MG/L/HR
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WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
0.0	0.0	32.0	32.0		100.0	12.79	9.95		0.40
0.0	0.37	33.5	33.5	33.5	109.1	12.41	9.80	11.11	2.04
0.02	0.78	33.3	33.3	33.3	109.1	12.28	10.01	11.14	2.00
0.04	1.20	33.2	33.2	33.2	109.2	12.17	10.19	11.18	1.97
0.06	1.61	33.1	33.1	33.1	109.2	12.08	10.36	11.22	1.94
0.08	2.02	32.9	32.9	32.9	109.3	12.01	10.50	11.25	1.91
0.10	2.44	32.8	32.8	32.8	109.3	11.95	10.64	11.29	1.88
0.12	2.85	32.8	32.8	32.8	109.4	11.91	10.76	11.33	1.85
0.14	3.26	32.7	32.7	32.7	109.4	11.88	10.87	11.38	1.82
0.16	3.68	32.6	32.6	32.6	109.4	11.86	10.98	11.42	1.79
0.18	4.09	32.5	32.5	32.5	109.5	11.84	11.08	11.46	1.76
0.20	4.50	32.5	32.5	32.5	109.5	11.84	11.17	11.50	1.74
0.22	4.92	32.4	32.4	32.4	109.6	11.57	10.91	11.24	1.71
0.24	5.33	32.4	32.4	32.4	109.6	11.31	10.65	10.98	1.68
0.26	5.74	32.3	32.3	32.3	109.6	11.06	10.40	10.73	1.66
0.28	6.16	32.3	32.3	32.3	109.7	10.81	10.16	10.49	1.63
0.30	6.57	32.3	32.3	32.3	109.7	10.57	9.93	10.25	1.61
0.32	6.99	32.2	32.2	32.2	109.8	10.34	9.70	10.02	1.58
0.34	7.40	32.2	32.2	32.2	109.8	10.11	9.48	9.80	1.56
0.36	7.81	32.2	32.2	32.2	109.8	9.89	9.27	9.58	1.54
0.38	8.23	32.2	32.2	32.2	109.9	9.68	9.06	9.37	1.51
0.40	8.64	32.2	32.2	32.2	109.9	9.47	8.85	9.16	1.49
0.42	9.06	32.1	32.1	32.1	110.0	9.27	8.66	8.96	1.47
0.44	9.47	32.1	32.1	32.1	110.0	9.07	8.46	8.77	1.44
0.46	9.88	32.1	32.1	32.1	110.1	8.88	8.28	8.58	1.42
0.48	10.30	32.1	32.1	32.1	110.1	8.70	8.10	8.40	1.40
0.50	10.71	32.1	32.1	32.1	110.1	8.52	7.93	8.22	1.38

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
0.52	11.13	32.1	32.1	32.1	110.2	8.34	7.76	8.05	1.36
0.54	11.54	32.1	32.1	32.1	110.2	8.17	7.59	7.88	1.34
0.56	11.96	32.1	32.1	32.1	110.3	8.01	7.43	7.72	1.32
0.58	12.37	32.1	32.1	32.1	110.3	7.85	7.28	7.57	1.30
0.60	12.79	32.0	32.0	32.0	110.3	7.70	7.13	7.42	1.28
0.62	13.20	32.0	32.0	32.0	110.4	7.55	6.99	7.27	1.26
0.64	13.62	32.0	32.0	32.0	110.4	7.41	6.85	7.13	1.24
0.66	14.03	32.0	32.0	32.0	110.5	7.27	6.72	6.99	1.22
0.68	14.45	32.0	32.0	32.0	110.5	7.13	6.59	6.86	1.20
0.70	14.86	32.0	32.0	32.0	110.6	7.00	6.46	6.73	1.19
0.72	15.28	32.0	32.0	32.0	110.6	6.88	6.34	6.61	1.17
0.74	15.69	32.0	32.0	32.0	110.6	6.76	6.22	6.49	1.15
0.76	16.11	32.0	32.0	32.0	110.7	6.64	6.11	6.37	1.13
0.78	16.52	32.0	32.0	32.0	110.7	6.52	6.00	6.26	1.12
0.80	16.94	32.0	32.0	32.0	110.8	6.41	5.89	6.15	1.10
0.82	17.35	32.0	32.0	32.0	110.8	6.31	5.79	6.05	1.08
0.84	17.77	32.0	32.0	32.0	110.8	6.20	5.69	5.95	1.07
0.86	18.18	32.0	32.0	32.0	110.9	6.10	5.60	5.85	1.05
0.88	18.60	32.0	32.0	32.0	110.9	6.01	5.51	5.76	1.03
0.90	19.01	32.0	32.0	32.0	111.0	5.91	5.42	5.67	1.02
0.92	19.43	32.0	32.0	32.0	111.0	5.82	5.33	5.58	1.00
0.94	19.84	32.0	32.0	32.0	111.0	5.74	5.25	5.49	0.99
0.96	20.26	32.0	32.0	32.0	111.1	5.65	5.17	5.41	0.97
0.98	20.68	32.0	32.0	32.0	111.1	5.57	5.09	5.33	0.96
1.00	21.09	32.0	32.0	32.0	111.2	5.49	5.02	5.25	0.94
1.02	21.51	32.0	32.0	32.0	111.2	5.41	4.94	5.18	0.93

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMP-ERATURE DAY DEG F	NIGHT DEG F	AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	NIGHT MG/L	AVG MG/L	AMMONIA LEVEL AVG MG/L
1.04	21.92	32.0	32.0	32.0	111.3	5.34	4.87	5.11	0.92
1.06	22.34	32.0	32.0	32.0	111.3	5.27	4.81	5.04	0.90
1.08	22.76	32.0	32.0	32.0	111.3	5.20	4.74	4.97	0.89
1.10	23.17	32.0	32.0	32.0	111.4	5.13	4.68	4.90	0.88
1.12	23.59	32.0	32.0	32.0	111.4	5.07	4.62	4.84	0.86
1.14	24.00	32.0	32.0	32.0	111.5	5.00	4.56	4.78	0.85
1.16	24.42	32.0	32.0	32.0	111.5	4.94	4.50	4.72	0.84
1.18	24.84	32.0	32.0	32.0	111.5	4.88	4.45	4.67	0.82
1.20	25.25	32.0	32.0	32.0	111.6	4.83	4.39	4.61	0.81
1.22	25.67	32.0	32.0	32.0	111.6	4.77	4.34	4.56	0.80
1.24	26.09	32.0	32.0	32.0	111.7	4.72	4.29	4.51	0.79
1.26	26.50	32.0	32.0	32.0	111.7	4.67	4.24	4.46	0.78
1.28	26.92	32.0	32.0	32.0	111.8	4.62	4.20	4.41	0.76
1.30	27.34	32.0	32.0	32.0	111.8	4.57	4.15	4.36	0.75
1.32	27.75	32.0	32.0	32.0	111.8	4.52	4.11	4.31	0.74
1.34	28.17	32.0	32.0	32.0	111.9	4.47	4.07	4.27	0.73
1.36	28.59	32.0	32.0	32.0	111.9	4.43	4.03	4.23	0.72
1.38	29.00	32.0	32.0	32.0	112.0	4.38	3.99	4.19	0.71
1.40	29.42	32.0	32.0	32.0	112.0	4.34	3.95	4.14	0.70
1.42	29.84	32.0	32.0	32.0	112.0	4.30	3.91	4.11	0.69
1.44	30.26	32.0	32.0	32.0	112.1	4.26	3.87	4.07	0.68
1.46	30.67	32.0	32.0	32.0	112.1	4.22	3.84	4.03	0.67
1.48	31.09	32.0	32.0	32.0	112.2	4.18	3.80	3.99	0.66
1.50	31.51	32.0	32.0	32.0	112.2	4.15	3.77	3.96	0.65
1.52	31.92	32.0	32.0	32.0	112.3	4.11	3.74	3.92	0.64
1.54	32.34	32.0	32.0	32.0	112.3	4.07	3.70	3.89	0.63

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	RIVER TEMPERATURE DAY DEG F	RIVER TEMPERATURE NIGHT DEG F	RIVER TEMPERATURE AVG DEG F	RIVER FLOW CFS	DISSOLVED OXYGEN LEVELS DAY MG/L	DISSOLVED OXYGEN LEVELS NIGHT MG/L	DISSOLVED OXYGEN LEVELS AVG MG/L	AMMONIA LEVEL AVG MG/L
1.56	32.76	32.0	32.0	32.0	112.3	4.04	3.67	3.86	0.62
1.58	33.18	32.0	32.0	32.0	112.4	4.01	3.64	3.82	0.61
1.60	33.59	32.0	32.0	32.0	112.4	3.97	3.61	3.79	0.60
1.62	34.01	32.0	32.0	32.0	112.5	3.94	3.58	3.76	0.59
1.64	34.43	32.0	32.0	32.0	112.5	3.91	3.55	3.73	0.58
1.66	34.85	32.0	32.0	32.0	112.5	3.88	3.53	3.70	0.57
1.68	35.27	32.0	32.0	32.0	112.6	3.84	3.50	3.67	0.57
1.70	35.68	32.0	32.0	32.0	112.6	3.81	3.47	3.64	0.56
1.72	36.10	32.0	32.0	32.0	112.7	3.78	3.44	3.61	0.55
1.74	36.52	32.0	32.0	32.0	112.7	3.75	3.42	3.58	0.54
1.76	36.94	32.0	32.0	32.0	112.8	3.72	3.39	3.56	0.53
1.78	37.36	32.0	32.0	32.0	112.8	3.69	3.36	3.53	0.52
1.80	37.77	32.0	32.0	32.0	112.8	3.67	3.34	3.50	0.52
1.82	38.19	32.0	32.0	32.0	112.9	3.64	3.31	3.47	0.51
1.84	38.61	32.0	32.0	32.0	112.9	3.61	3.28	3.45	0.50
1.86	39.03	32.0	32.0	32.0	113.0	3.58	3.26	3.42	0.49
1.88	39.45	32.0	32.0	32.0	113.0	3.55	3.23	3.39	0.49
1.90	39.87	32.0	32.0	32.0	113.1	3.52	3.21	3.36	0.48
1.92	40.28	32.0	32.0	32.0	113.1	3.49	3.18	3.34	0.47
1.94	40.70	32.0	32.0	32.0	113.1	3.46	3.15	3.31	0.47
1.96	41.12	32.0	32.0	32.0	113.2	3.43	3.13	3.28	0.46
1.98	41.54	32.0	32.0	32.0	113.2	3.40	3.10	3.25	0.45

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.0	0.0	2.00	0.50	2.50	0.55	3.04	3.00	0.40	0.10
0.0	0.37	6.72	0.55	7.27	2.78	10.05	3.58	2.87	8.43
0.02	0.78	6.57	0.57	7.13	2.74	9.87	3.54	2.85	8.05
0.04	1.20	6.40	0.58	6.98	2.70	9.68	3.50	2.84	7.69
0.06	1.61	6.24	0.59	6.84	2.65	9.49	3.46	2.82	7.34
0.08	2.02	6.09	0.61	6.70	2.61	9.31	3.43	2.81	7.01
0.10	2.44	5.94	0.62	6.56	2.57	9.13	3.39	2.79	6.69
0.12	2.85	5.79	0.64	6.43	2.53	8.96	3.35	2.78	6.40
0.14	3.26	5.65	0.65	6.30	2.49	8.79	3.31	2.76	6.11
0.16	3.68	5.52	0.67	6.18	2.45	8.63	3.28	2.75	5.84
0.18	4.09	5.38	0.68	6.07	2.41	8.48	3.24	2.73	5.58
0.20	4.50	5.26	0.69	5.95	2.38	8.33	3.20	2.72	5.33
0.22	4.92	5.13	0.71	5.84	2.34	8.18	3.17	2.70	5.10
0.24	5.33	5.01	0.72	5.74	2.30	8.04	3.13	2.69	4.87
0.26	5.74	4.89	0.74	5.63	2.27	7.90	3.10	2.67	4.66
0.28	6.16	4.78	0.75	5.53	2.23	7.77	3.06	2.66	4.45
0.30	6.57	4.67	0.77	5.44	2.20	7.64	3.03	2.64	4.25
0.32	6.99	4.56	0.78	5.34	2.17	7.51	3.00	2.63	4.07
0.34	7.40	4.46	0.80	5.25	2.13	7.39	3.00	2.62	3.89
0.36	7.81	4.35	0.81	5.17	2.10	7.27	3.00	2.60	3.72
0.38	8.23	4.26	0.83	5.08	2.07	7.15	3.00	2.59	3.55
0.40	8.64	4.16	0.84	5.00	2.04	7.04	3.00	2.58	3.40
0.42	9.06	4.06	0.85	4.92	2.01	6.93	3.00	2.56	3.25
0.44	9.47	3.97	0.87	4.84	1.98	6.82	3.00	2.55	3.11
0.46	9.88	3.88	0.88	4.77	1.95	6.71	3.00	2.53	2.97
0.48	10.30	3.80	0.90	4.70	1.92	6.61	3.00	2.52	2.84
0.50	10.71	3.71	0.91	4.63	1.89	6.51	3.00	2.51	2.72

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES., 10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUNDARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROGENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
0.52	11.13	3.63	0.93	4.56	1.86	6.42	3.00	2.50	2.60
0.54	11.54	3.55	0.94	4.49	1.83	6.32	3.00	2.48	2.48
0.56	11.96	3.47	0.96	4.43	1.80	6.23	3.00	2.47	2.37
0.58	12.37	3.39	0.97	4.37	1.78	6.14	3.00	2.46	2.27
0.60	12.79	3.32	0.99	4.31	1.75	6.06	3.00	2.44	2.17
0.62	13.20	3.25	1.00	4.25	1.72	5.97	3.00	2.43	2.08
0.64	13.62	3.18	1.02	4.20	1.70	5.89	3.00	2.42	1.99
0.66	14.03	3.11	1.03	4.14	1.67	5.81	3.00	2.40	1.90
0.68	14.45	3.04	1.05	4.09	1.65	5.74	3.00	2.39	1.82
0.70	14.86	2.98	1.06	4.04	1.62	5.66	3.00	2.38	1.74
0.72	15.28	2.91	1.08	3.99	1.60	5.59	3.00	2.37	1.66
0.74	15.69	2.85	1.09	3.94	1.57	5.52	3.00	2.35	1.59
0.76	16.11	2.79	1.11	3.90	1.55	5.45	3.00	2.34	1.52
0.78	16.52	2.73	1.12	3.85	1.53	5.38	3.00	2.33	1.45
0.80	16.94	2.67	1.14	3.81	1.50	5.31	3.00	2.32	1.39
0.82	17.35	2.61	1.15	3.77	1.48	5.25	3.00	2.31	1.33
0.84	17.77	2.56	1.17	3.73	1.46	5.19	3.00	2.29	1.27
0.86	18.18	2.50	1.18	3.69	1.44	5.13	3.00	2.28	1.21
0.88	18.60	2.45	1.20	3.65	1.41	5.07	3.00	2.27	1.16
0.90	19.01	2.40	1.21	3.62	1.39	5.01	3.00	2.26	1.11
0.92	19.43	2.35	1.23	3.58	1.37	4.95	3.00	2.25	1.06
0.94	19.84	2.30	1.25	3.55	1.35	4.90	3.00	2.23	1.02
0.96	20.26	2.25	1.26	3.51	1.33	4.85	3.00	2.22	0.97
0.98	20.68	2.21	1.28	3.48	1.31	4.79	3.00	2.21	0.93
1.00	21.09	2.16	1.29	3.45	1.29	4.74	3.00	2.20	0.89
1.02	21.51	2.12	1.31	3.42	1.27	4.70	3.00	2.19	0.85

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.04	21.92	2.07	1.32	3.39	1.25	4.65	3.00	2.18	0.81
1.06	22.34	2.03	1.34	3.37	1.23	4.60	3.00	2.16	0.78
1.08	22.76	1.99	1.35	3.34	1.22	4.56	3.00	2.15	0.74
1.10	23.17	1.95	1.37	3.32	1.20	4.51	3.00	2.14	0.71
1.12	23.59	1.91	1.38	3.29	1.18	4.47	3.00	2.13	0.68
1.14	24.00	1.87	1.40	3.27	1.16	4.43	3.00	2.12	0.65
1.16	24.42	1.83	1.41	3.25	1.14	4.39	3.00	2.11	0.62
1.18	24.84	1.79	1.43	3.22	1.13	4.35	3.00	2.10	0.59
1.20	25.25	1.76	1.45	3.20	1.11	4.31	3.00	2.09	0.57
1.22	25.67	1.72	1.46	3.18	1.09	4.28	3.00	2.08	0.54
1.24	26.09	1.69	1.48	3.16	1.08	4.24	3.00	2.06	0.52
1.26	26.50	1.65	1.49	3.15	1.06	4.21	3.00	2.05	0.50
1.28	26.92	1.62	1.51	3.13	1.05	4.17	3.00	2.04	0.48
1.30	27.34	1.59	1.52	3.11	1.03	4.14	3.00	2.03	0.45
1.32	27.75	1.55	1.54	3.09	1.01	4.11	3.00	2.02	0.44
1.34	28.17	1.52	1.56	3.08	1.00	4.08	3.00	2.01	0.42
1.36	28.59	1.49	1.57	3.06	0.98	4.05	3.00	2.00	0.40
1.38	29.00	1.46	1.59	3.05	0.97	4.02	3.00	1.99	0.38
1.40	29.42	1.43	1.60	3.04	0.95	3.99	3.00	1.98	0.36
1.42	29.84	1.41	1.62	3.02	0.94	3.96	3.00	1.97	0.35
1.44	30.26	1.38	1.63	3.01	0.93	3.94	3.00	1.96	0.33
1.46	30.67	1.35	1.65	3.00	0.91	3.91	3.00	1.95	0.32
1.48	31.09	1.32	1.67	2.99	0.90	3.89	3.00	1.94	0.30
1.50	31.51	1.30	1.68	2.98	0.89	3.86	3.00	1.93	0.29
1.52	31.92	1.27	1.70	2.97	0.87	3.84	3.00	1.92	0.28
1.54	32.34	1.25	1.71	2.96	0.86	3.82	3.00	1.91	0.27

WATER QUALITY IN SURFACE WATERS FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS : 1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

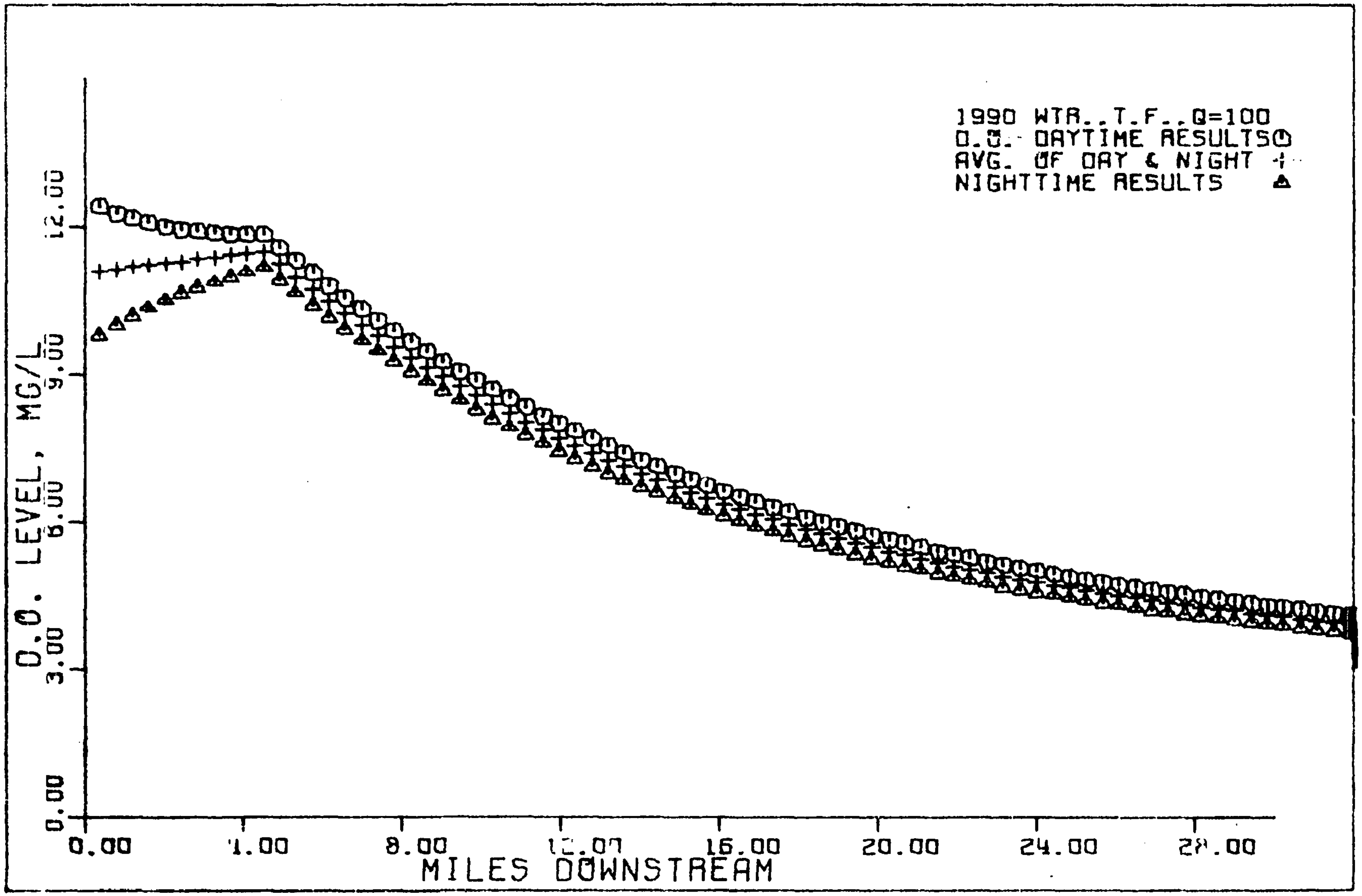
TIME OF TRAVEL DAYS	DISTANCE DOWN-STREAM MILES	AVERAGE LEVEL OF BOD IN RIVER: EFFLUENT BOD MG/L	BOUND-ARY-BOD MG/L	TOTAL CBN-BOD MG/L	NITROG-ENOUS-BOD MG/L	TOTAL BOD MG/L	NITRATE LEVEL NO3-N MG/L	PHOSPHATE LEVEL PO4 MG/L	COLIFORM INDEX, PERCENT REMAINING
1.56	32.76	1.22	1.73	2.95	0.85	3.80	3.00	1.90	0.25
1.58	33.18	1.20	1.74	2.94	0.83	3.78	3.00	1.89	0.24
1.60	33.59	1.17	1.76	2.93	0.82	3.76	3.00	1.88	0.23
1.62	34.01	1.15	1.78	2.93	0.81	3.74	3.00	1.87	0.22
1.64	34.43	1.13	1.79	2.92	0.80	3.72	3.00	1.86	0.21
1.66	34.85	1.11	1.81	2.91	0.79	3.70	3.00	1.85	0.20
1.68	35.27	1.09	1.82	2.91	0.77	3.68	3.00	1.84	0.20
1.70	35.68	1.06	1.84	2.90	0.76	3.67	3.00	1.83	0.19
1.72	36.10	1.04	1.86	2.90	0.75	3.65	3.00	1.82	0.18
1.74	36.52	1.02	1.87	2.89	0.74	3.63	3.00	1.81	0.17
1.76	36.94	1.00	1.89	2.89	0.73	3.62	3.00	1.80	0.16
1.78	37.36	0.98	1.90	2.89	0.72	3.60	3.00	1.79	0.16
1.80	37.77	0.96	1.92	2.88	0.71	3.59	3.00	1.78	0.15
1.82	38.19	0.95	1.93	2.88	0.70	3.58	3.00	1.77	0.14
1.84	38.61	0.93	1.95	2.88	0.69	3.56	3.00	1.76	0.14
1.86	39.03	0.91	1.97	2.88	0.68	3.55	3.00	1.76	0.13
1.88	39.45	0.89	1.98	2.87	0.67	3.54	3.00	1.75	0.13
1.90	39.87	0.87	2.00	2.87	0.66	3.53	3.00	1.74	0.12
1.92	40.28	0.86	2.01	2.87	0.65	3.52	3.00	1.73	0.11
1.94	40.70	0.84	2.03	2.87	0.64	3.51	3.00	1.72	0.11
1.96	41.12	0.82	2.05	2.87	0.63	3.50	3.00	1.71	0.10
1.98	41.54	0.81	2.06	2.87	0.62	3.49	3.00	1.70	0.10

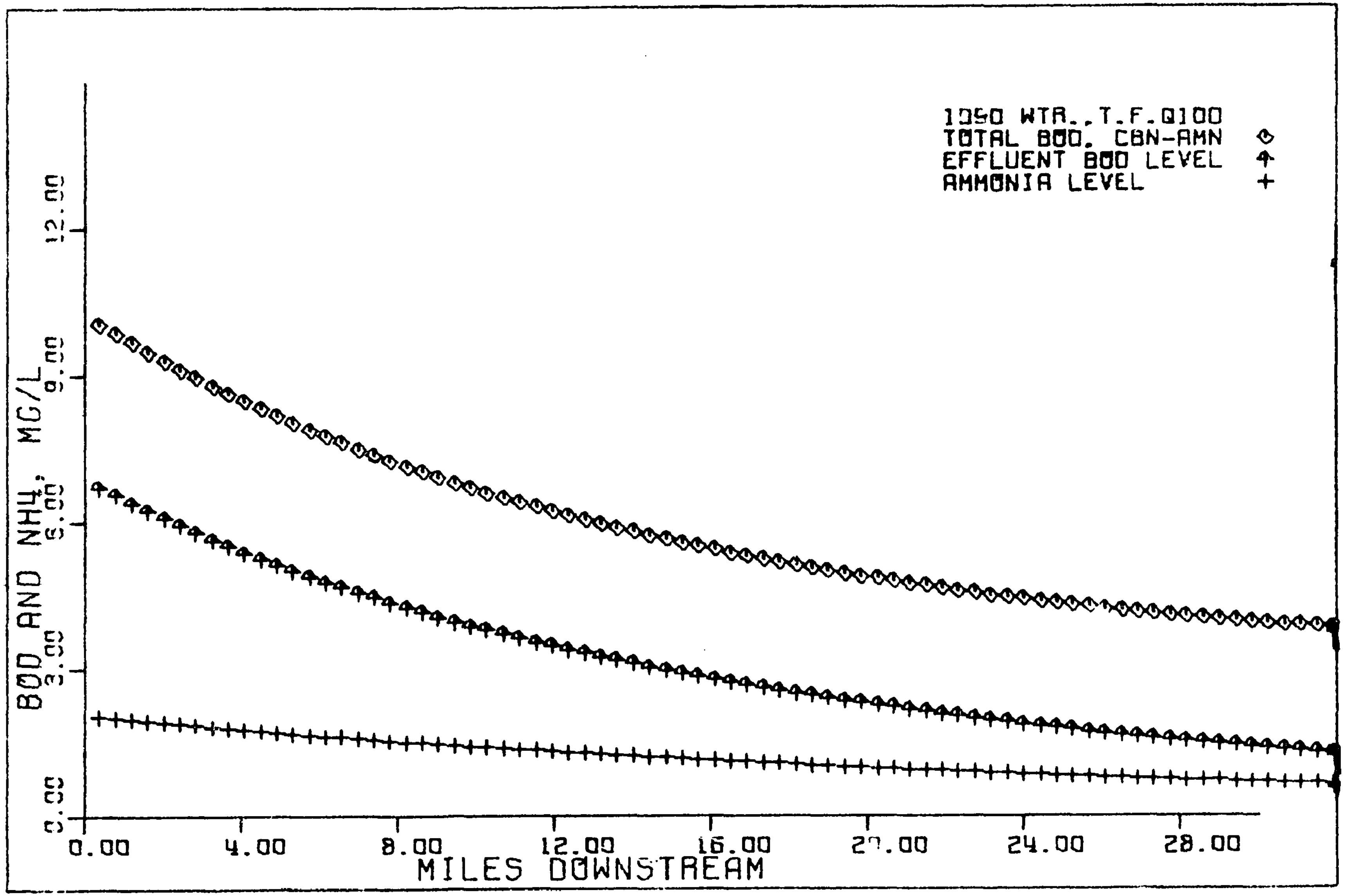
WATER QUALITY IN SURFACE WATERS
FOR SELECTED PARAMETERS

STREAM : SKUNK RIVER, DOWNSTREAM OF AMES, WPCP AT MILE 0.37
CONDITIONS :
1990 DESIGN CONDITIONS, TRICKLING FILTER AND AMES RES.,10-YR
SEASON : WINTER
BOD RESULTS ARE FOR SIMULATED 5-DAY BOD VALUES

SUMMARY OF RESULTS FOR THE ASSIMILATIVE REACH, 2*TAUTM DAYS

	DAYTIME VALUES			NIGHTTIME VALUES		
	VALUE	MILE	DAY	VALUE	MILE	DAY
DISSOLVED OXYGEN						
INITIAL, MG/L	12.41	0.37	0.0	9.80	0.37	0.0
MINIMUM DO, MG/L	3.40	41.54	1.98	3.10	41.54	1.98
FINAL DO, MG/L	6.41	16.94	0.80	5.89	16.94	0.80
DO DEFICIT						
INITIAL, MG/L	1.48	0.37	0.0	4.08	0.37	0.0
FINAL, MG/L	7.80	16.94	0.80	8.31	16.94	0.80
RIVER DISCHARGE						
INITIAL, CFS	109.10	0.37	0.0	109.10	0.37	0.0
FINAL, CFS	110.76	16.94	0.80	110.76	16.94	0.80
RIVER TEMPERATURE						
INITIAL, DEG F	33.50	0.37	0.0	33.50	0.37	0.0
FINAL, DEG F	32.02	16.94	0.80	32.02	16.94	0.80
EFFLUENT BOD IN RIVER						
INITIAL BOD,MG/L	6.72	0.37	0.0	6.72	0.37	0.0
FINAL BOD, MG/L	2.67	16.94	0.80	2.67	16.94	0.80
BOUNDARY BOD ADDITIONS						
VALUE PER MI-DAY,MG/L	0.03	0.37	0.0	0.03	0.37	0.0
FINAL BOD IN RIVER	1.12	16.94	0.80	1.16	16.94	0.80
NITROGENOUS BOD						
INITIAL BOD, MG/L	2.78	0.37	0.0	2.78	0.37	0.0
FINAL BOD, MG/L	1.50	16.94	0.80	1.50	16.94	0.80
TOTAL CBN & NITR BOD LEVEL						
INITIAL VALUE, MG/L	9.99	0.37	0.0	10.10	0.37	0.0
FINAL VALUE, MG/L	5.29	16.94	0.80	5.34	16.94	0.80
AMMONIA NITROGEN						
INITIAL VALUE, MG/L	2.04	0.37	0.0	2.04	0.37	0.0
FINAL VALUE, MG/L	1.10	16.94	0.80	1.10	16.94	0.80
NITRATE (NO2-NO3) NITROGEN						
INITIAL VALUE, MG/L	3.58	0.37	0.0	3.58	0.37	0.0
FINAL VALUE, MG/L	3.00	16.94	0.80	3.00	16.94	0.80
PHOSPHATE PO4 LEVEL						
INITIAL VALUE, MG/L	2.87	0.37	0.0	2.87	0.37	0.0
FINAL VALUE, MG/L	2.32	16.94	0.80	2.32	16.94	0.80
COLIFORM INDEX, % REMAINING						
INITIAL PERCENT	8.43	0.37	0.0	8.43	0.37	0.0
FINAL PERCENT	1.39	16.94	0.80	1.39	16.94	0.80


1990 WTR..T.F..Q=100
D.O. DAYTIME RESULTS
AVG. OF DAY & NIGHT
NIGHTTIME RESULTS
D.O. LEVEL, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM



1990 WTR.,T.F.Q100
TOTAL BOD. CBN-AMN
EFFLUENT BOD LEVEL
AMMONIA LEVEL
BOD AND NH4, MG/L
0.00
3.00
6.00
9.00
12.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
MILES DOWNSTREAM