1972

Economics of water quality management;exemplified by specified pollutants in agricultural runoff

James Jerome Jacobs
Iowa State University

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JACOBS, James Jerome, 1943-
ECONOMICS OF WATER QUALITY MANAGEMENT:
EXEMPLIFIED BY SPECIFIED POLLUTANTS IN
AGRICULTURAL RUNOFF.

Iowa State University, Ph.D., 1972
Economics, general

Economics of water quality management: Exemplified by specified pollutants in agricultural runoff

by

James Jerome Jacobs

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

Major Subject: Economics

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1972

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CHAPTER I. INTRODUCTION

This study seeks to depict the role of economics in environmental quality management, with particular reference to the optimal level of water quality for a particular use area. Each use of water affects the constituents[1] present in water and thus its quality. In turn, each use of water demands certain desired levels of constituents, i.e., "water quality." Therefore, the establishment of water quality levels may affect the use patterns of the water resource. This suggests that "water quality" has no absolute definition but, as others have indicated (18, p. 3; 58, p. 379; 91, p. 189), can be measured only against the uses to which the water resource is to be put.

Thus, the problem of quality arises from the conflicting quality impacts and requirements between uses. In view of the ever-increasing use and reuse of natural resources, resource users have begun to realize that the acceptability and adequacy of a resource is governed by quality as well as quantity. This realization, accentuated by public interest in the natural environments, has led to the present emphasis on controlling the quality of the environment to enhance man's welfare.

Growing Importance and Nature of Environmental Quality

The growing public concern over the deterioration of the environment is the result of the transformation that has occurred in public

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[1] The term constituents refers to the elements present in water, such as chloride, nitrates, phosphates, temperature, etc., which determine water quality.

attitude about "the physical environment." One scientist describes the shift this way: ". . . first an island of anxiety about specific environmental ills -- like the redwoods, the rivers, or the slums -- rose from a sea of apathy; when they rose further, land appeared between them; we became aware that all these separate environmental issues were connected, all part of a single challenge to our civilization" (79, p. 91). The public has begun to realize the interrelationship of all living things -- including man -- with the environment (22, p. 6). This public interest along with political motivation and the enactment of laws emphasize environmental quality as a major national issue now and in future years. Concern for the environment is expressed by the title of Fortune's special issue in February, 1970: "The Environment: A National Mission for the Seventies." President Nixon, in his message to Congress in August of 1970 states ". . . this represents the first time in the history of nations that a people has paused, consciously and systematically, to take comprehensive stock of the quality of its surroundings" (22, p. v).

From this concern regarding the natural environment, the national goal of seeking appropriate means for lessening the degradation of natural resources and enhancing environmental quality has emerged. Improved environmental quality has successfully laid claim to a place in the array of major national objectives (38, p. 1). While such a goal is commendable, there exists a need to define environment and to develop quality standards for the natural environment which could be agreed upon and serve as a recognizable national goal (100, p. 1). Until environmental quality can be defined, improving environmental quality as a national goal and the means to achieve it will remain abstruse, dubious, and subjective. Unless we can establish relevant quality standards and demonstrate means to achieve them, there is a danger that increased public awareness will cause action to move faster than our factual basis for action and public understanding of the facts will accommodate. Then, our apparent public concensus in support of improving environmental quality today may turn out to be a very weak confederation as the facts (costs and effects) are brought to bear on individuals.[1]

Therefore, concerns and means for improving our natural environment must be based on facts obtained through research and education to provide foundations on which action may be formulated and implemented. Action dealing with the establishment of a national policy on environmental quality is faced with the twofold problem of (1) development of a means for establishing relevant quality levels and (2) a system to explore the methods for achieving these levels. The establishment of quality standards has already been initiated by government agencies within particular natural resources such as soil, air, and water (49, 110, 111, 112).

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[1] For a discussion of conflicts between environmental quality as a goal versus other national goals, see Timmons (100, p. 1-3).

In establishing relevant environmental quality levels, three relationships between uses of a resource, with respect to quality, can be identified. These relationships, (1) neutral, (2) complementary, and (3) competitive (101, p. 39), are essential in setting quality levels.

A neutral relationship exists between uses when one use has no effect on other uses. Under complementary relationships, one use improves the quality for another use. In both of the above cases, no quality conflicts exist between uses so no decisions are called for as far as quality is concerned.

Competitive relationships between uses exist when one use impairs the quality desired by other uses. These relationships are the core of our quality management problems. Where these competitive quality uses exist, decisions are required to resolve the conflict between uses.

Importance of Water Quality as Related to Water Uses

Water quality is one important component of our environment. The national concern over the quality of our water is evident in the outpouring of information from popular media (79, 94, 40), in articles and proceedings of symposia by scholars (12, 125, 80, 17, 57), in reports of planning groups (52, 68, 109, 22), and in statutes (49, 110) of the past few years (85, p. 1).

The problem of water quality has grown to two major levels of concern. The first level of concern is with the public health being threatened or actually impaired through contamination of our water resources. The second level of concern augmented by the increasing use of water resources consists of damages inflicted on one or more beneficial uses by a change in the quality of water.

Emergence of quantity-quality problem

Traditionally, the development of water resources in the United States has been directed primarily toward quantity aspects, i.e. floods, droughts, and sufficient volume for beneficial uses. During recent years, the nation has become increasingly aware of the fact that the total supply of fresh water in any geographical area is limited by hydrological phenomena, i.e., rainfall, evaporation, etc., while the demand for this water is continually increasing with population growth, urbanization, industrialization, and the expansion of irrigated agriculture (68, p. 4). The consequence of these future water requirements is that there will be a continually increasing reuse and reallocation of our fresh water supply. One authority states that ". . . reuse is an especially intriguing problem for the economist because different uses of the same resource commonly have different effects on quality and, in turn, have different quality requirements. Thus, quality management has to deal with a multiple-use problem of a particular sort, namely with the sequence of different uses over time. Some problems of the quantitative allocation of resources among different uses appear in a new light if differences in quality effects and quality requirements are taken into account" (20, p. 1133). This means that the quality effects and requirements of uses should be considered if the reuse and reallocation of a water supply among uses is to maximize productivity.

Because water incorporates, to some extent, everything it comes in contact with, its every use, whether natural, industrial, or domestic has some effect on its constituents. This causes constituents and their quality levels to vary among water supplies. Since different water uses demand different constituents in water or at least vary in their tolerance of particular constituents, the "quality mix" of a particular supply must be appraised in terms of the use or uses to which it is to be put. Consequently, there are two fundamental characteristics of the supply of and demand for water insofar as quality is concerned. These are (1) quality heterogeneity of water supplies and (2) quality differentiation of demands according to uses (101, p. 38). Therefore, in approximating demands for and supplies of water for future years, these approximations should be differentiated in terms of (1) amounts of quality linked supplies and demands, (2) spatial occurrence of quality linked supplies and demands, and (3) temporal occurrences of quality linked supplies and demands (104, p. 48). This veritably indicates that quality is becoming as important as quantity in the management of the nation's water resources, if not more so. Thus, the water quality management problem is one of determining the appropriate quality of a water supply in view of the differentiated quality requirements of water use or uses of that supply at a given location and time.

Linkage of conflicting water quality uses

Realizing the quality heterogenity of our water supplies and demands, stated earlier, there is an increasing awareness of the fact that scarcity of water resources is largely a function of quality. Qualities of water may be the result of processes associated with uses of modern technology by man and/or produced by the natural environment. Indeed, even before man's inhabitance, watercourses received the waste products of plant and animal life together with the sediment from natural erosion. Therefore, our watercourses have always served as a transport system for a variety of constituents. Furthermore, the carriage and dilution of waste constituents have been cited as a beneficial use of watercourses (106, p. 668).

The watercourse, as a carriage system for waste constituents, is an extremely complex system. The quality control and management of such a system requires the following information: (1) understanding of the stream's characteristics and its in-stream processes, (2) effects of particular uses on the constituents and the associated quality of a watercourse, and (3) identification of the impact of water quality on the "next-use(s)." This information is strategic in analyzing the effects of waste constituents from a particular source, such as agricultural runoff, on water quality and the gearing of supply qualities to demand qualities of subsequent uses. In this type of analysis, the water carriage or transport system serves as the linkage, in a physical sense, between various uses of the water supply. It is the linkage mechanism that provides the conditions needed for the possible existence of off-site or external effects, which has important economic implications.[1]

Problem of Determination and Measurement of Water Qualities

Next-use and water quality in an economic context

Economics is primarily concerned with the decision making process in allocating scarce resources among competing ends. Specifically, it constitutes a basis for identifying and efficiently implementing choices regarding the allocation of scarce resources among competing ends. In this context, a water supply may be regarded as an economic resource only when it exhibits the characteristic of scarcity and thereby needs to be allocated among competing ends. Economic scarcity need not relate to physical quantity only, if one views water supplies as heterogenous entities. In fact, as was indicated earlier, water supplies as well as water demands should be differentiated in terms of quality as well as by time and space (104, pp. 47-49). Therefore, water supplies and demands are quality differentiated. Each supply and demand component is affected with a set of physical, chemical, and/or biological parameters.

Viewed in this manner, a water supply with a particular quality may serve a number of demands unequally well. Since different uses generally require different constituents or levels of a particular constituent,

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[1] The economic implications of external effects will be discussed in Chapter III.

water quality is regarded as a demand-oriented concept. For example, dissolved oxygen is essential for fish and other aquatic life but may be detrimental in cooling water because of the increased corrosion associated with high oxygen levels (69, p. 180). Therefore, as mentioned earlier, quality of a water supply must be assessed in terms of a particular use or uses of that supply.

Furthermore, the waste constituents from one use may affect the quality of a water supply such that it increases the cost to or precludes the next use of that supply. This constitutes water pollution,[1] which is a supply-oriented concept. In an economic context, it means a change in one or more of the constituents of a water supply such that additional costs must be borne by the next user to meet the quality constituents required by his use. Stated another way, water pollution is a problem involving external diseconomies. This means that the initial use did not absorb the full cost of its effluent's effect on the quality of the water, but shifted the cost to a subsequent use.

What does this have to do with the problem of establishing the quality of a water supply in the face of varying water quality demands? The existence of varying quality demands by water uses means that in an economic context, water quality is a relative rather than an absolute concept. Thus, water quality should be related to the use to be made of water rather than to some deviation from a level designated as the

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[1] In this study, a waste constituent is regarded as a pollutant only when it has an adverse effect on subsequent uses.

"natural state" (85, p. 3).

This suggests that in defining pollution and establishing water quality levels, there is a need to consider the next uses(s). Tarzwell states it this way: ". . . when water quality requirements for each water use are established, they will provide us with a definition of what constitutes pollution and a base line which can be used for detection and evaluation of pollution in specific areas" (91, p. 189). Knowing the quality requirements of subsequent uses, the need for remedial action could be determined. Professor Timmons states, ". . . the next use test, holds that undesirable changes or pollution occur when the effluent or effect of an initial use adversely affects the next use to which the resource, i.e., water, may be put in meeting needs of people," (100, p. 81). This indicates that degradation or pollution occur when the effluent of one use adversely affects the next use(s) to which the water resource may be put. If the initial use has no adverse effect on the next uses, then there is no pollution problem and no need for establishing water quality levels. However, if the initial use creates adverse effects on one or more of the next uses, water quality levels should be established and they should reflect the costs to the next use as well as the benefits to the preceding use. This concept is termed the "Next-Use Approach to Water Quality Management." The next-use test means that quality levels of a water supply will vary from time to time, from area to area, and from use to use, depending upon the quality requirements of the next use(s) of that supply. This concept is also helpful in minimizing the costs of obtaining quality levels, whereby quality criteria (requirements) of uses can be expressed in physical terms and regarded as proxies for societal goals (85, pp. 8-9); thereby treating them as constraints upon the cost minimization objective.

Competitive nature of water quality problems

In the "Next-Use Approach to Water Quality Management," water quality levels need to be established only where a preceding use adversely affects one or more of the subsequent uses. When one use impairs the water quality desired by another use, a competitive relationship exists between water quality uses. These competitive relationships are the core of our water quality problems and decisions are required to resolve the conflict among water uses. In view of the quality heterogeneity of water supplies by natural and man-related uses and the quality differentiated water uses stated above, these water quality decisions are faced with the twofold problem of (1) determining the appropriate quality level for a water supply entity[1] and (2) seeking the best means of achieving that level. The remedial hypothesis is that the next use concept can be used in establishing relevant quality levels for a water supply and in minimizing the cost of obtaining these quality levels.

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[1] A water supply entity is regarded here as the decision making unit (i.e., river basin or water resource region) concerned with optimizing all uses of a scarce water supply.

Under the "next use approach" for evaluating the effects of agricultural pollutants, we need to identify and measure the waste constituents of agriculture and the constituents desired (quality criteria) by the next use(s). By linking the constituents which agriculture affects and the constituents which the next use(s) desire, we can establish the relevant constituents and their quality levels. Strategic then to analyzing agriculture's role in water quality management is: (1) the identification and measurement of agricultural pollutants associated with various agricultural practices, (2) the identification of next uses and their water quality criteria and (3) the specification of the physical linkage system. Only with this type of information can agriculture's contribution to water quality changes be determined and evaluated in a relevant manner.

Study Objectives

The significance of quality in the reuse and reallocation of water for the future has increased the attention and efforts devoted to the quality problem. This study proposes to examine that aspect of our water quality problem concerning methods and procedures for developing relevant quality levels for a water supply entity. (Specifically), sediment and phosphorus introduced into a surface water course from agricultural runoff will serve as an exemplary basis to establish relevant quality levels and to estimate the least-cost means of achieving these levels. In addition, the necessary physical, economic, and institutional components of such a water quality management system will be examined.

In exploring the problem of setting water quality levels, the study seeks to achieve the following objectives in attempting to comprehend and alleviate this problem:

(1) to develop a basis for establishing quality levels of a water supply,

(2) to formulate a method for estimating least-cost means of achieving particular quality levels,

(3) to apply this method to selected alternative water quality management practices,

(4) to suggest the physical, economic, and institutional components of water quality management systems, and

(5) to suggest future research needs in water quality management.

The first objective requires the specification of physical, biological, and economic aspects and relationships as required to measure the impact of a particular activity on water quality and thereby on the following use(s). The physical, biological, and economic framework must include the following: (1) identification and measurement of waste constituents by uses, (2) relationship between waste constituents, (3) quality criteria of potential uses of the supply, (4) relationship between constituent levels and their impact on water quality and thereby on water uses, and (5) the physical linkage of water uses.

The second and third objectives assume that conflicting water quality levels can be reconciled by a variety of abatement techniques and that different costs are associated with each one.

The fourth objective examines the necessary components of a water quality management system to achieve the first two objectives. This includes the identification of supplies and demands by quality parameters, estimation of benefits and costs associated with quality levels and appropriate institutional forms. Fifth, further research needs suggested by the analysis will be presented.

Methods and Procedures of Study

Analytical technique

The analytical methods used in this analysis are concerned with establishing quality levels by identifying and analyzing quality-differentiated supplies and demands for water in a watercourse. Information from agronomic and engineering sciences are relied upon in estimating sediment and phosphorus losses in runoff from agriculturel land, the relationship between these constituents, and their movement down the watercourse. These approximations represent the present "state of the art" and will undoubtedly require several simplifying assumptions where sufficient data and/or concensus are lacking. This physical system provides for the linkage between water uses of the watercourse.

The quality control measures considered are land practices and abatement techniques, with effectiveness and cost data provided by the same disciplines mentioned above.

Water quality requirements of alternative uses are reflected in discrete quality levels and regarded as constraints in a linear programming model to calculate the least cost method of obtaining that quality level.

The physical system, improvement techniques, and use consequences and requirements are basic to the approach in this analysis and to achieving the objectives of the study.

Application of the approach

The applications of the next use concept will be demonstrated in a highly simplified river basin in western Iowa. This is the Nishnabotna River Basin for which data on land and water uses are available. Furthermore, there are four experimental watersheds in the basin which are being analyzed for sediment losses and runoff under different land practices. These data will be used to represent and analyze the study area. Some simplifying assumptions, such as the experimental watersheds being representative of the basin, a uniform soil type, and the existence of only a few selective water uses, will be made. These simplifications of the basin mean that the empirical results of the study are not directly applicable to the Nishnabotna basin. Despite these limitations, the importance and relevance of the study lies in its analytical approach to and the specification of data needed for water quality management.

Organization of Report

The first chapter presents the problem to be studied, the objectives of the study and the procedures to be used. The next use concept as a means to determine and manage water quality is also developed. In developing this concept, water quality use relationships are identified, the linkage of water uses is discussed, and the problems of water quality abatement and pollution are presented in an economic context.

The importance and role of agriculture in water quality management and alternative means of water quality management are discussed in Chapter II. Chapter III concerns itself with the scope and dimensions of water quality management. In Chapter IV, the analytical techniques and model are developed. The application of the constrained cost minimization model to the study area and the results are presented in Chapter V. The measurement of benefits from quality management and the components of a water quality management system are proposed and discussed in Chapter VI, while Chapter VII is devoted to future research needs and an evaluation and summary of the study.

CHAPTER II. AGRICULTURE'S ROLE IN WATER QUALITY MANAGEMENT

Potential of Agriculture in Water Quality Management

Recent upsurge of public concern over environmental questions has brought all potential pollution sources under suspect, and agriculture is no exception. The major purpose of agriculture is to manage resources in order to produce the food and fiber demanded by mankind (1, p. 1). Therefore, agricultural production and environmental research is not new. In the past, however, this research has concentrated on efforts to increase the production of food and fiber which has largely ignored the effects of production on the environment. This effort to increase production and improve efficiency was accepted by society as a means to reduce food costs and increase farm income (67, p. 1). Now this same society is asking all segments, including agriculture, to reassess their role in environmental quality.

The agriculture industry comprises, perhaps, the largest environmental complex of any water using sector (6, p. 1). Therefore, its potential in affecting and enhancing the quality of our waters is universal and significant. Professor Timmons states ". . . of all the industries in the United States, agriculture possesses the greatest potential for affecting the quality of the nation's water resources" (99, p. 377). This statement is substantiated by the fact that sediment appears to be the largest single pollutant of our nation's surface waters (14, 42, 82), exceeding the suspended solids caused by sewage discharge at least 700 times (108). Wadleigh (121, p. 24) estimated that four billion tons of sediment is delivered to our surface waters annually and that 75 per cent comes from forested and agricultural lands. In the past, the primary concern of erosion was for the reduction in soil productivity. Today, with the quality of our environment receiving national attention, sediment with its physical, chemical, and biological implications is being assessed in terms of its effect on the environment. Following a simple chain of reasoning: sediment with its concomitant properties and load of elements is at least a potential hazard to water quality (6, p. 8). Since agriculture is the major contributor to sediment losses, its activities in soil, crop, livestock, and water management exhibit, perhaps, the greatest potential for affecting and enhancing the quality of our water resources. This potential and responsibility of agriculture in water quality management arises primarily from the combination of: (1) the fact that agriculture production is scattered over most of the nation's surface and (2) the use of modern technologies with their residues and fallouts.

The degradation of our surface water by domestic sewage and industrial waste, which can be termed as "point sources,"[1] has long been recognized by society. While agriculture's potential of polluting our surface waters is recognized, little is known about agriculture's share in the

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[1] Point sources of waste constituents, such as the outfall from industrial and municipal treatment plants, are characterized by the ease with which the point of entry of the wastes can be pinpointed.

responsibility for the water quality problem. Our ignorance of agriculture's role in water quality control lies in its diffuse source[1] of waste constituents and the relative newness and rapid rate of adoption of modern technologies in agriculture. At first, agriculture approached a closed system, receiving few inputs from other sectors and exporting small amounts of food. With the commercialization and technological changes in agriculture in the past few decades, it has become more and more interdependent with other sectors in our economy. As agriculture's utilization of modern technologies continued in striving for greater efficiencies of production, the production systems became more intensified and its potential for affecting the environment increased. Thus, the modern technologies of concentrated livestock production, pesticide use, fertilization of crops, and tillage practices all contribute to the water quality problem.

Agriculture as a Source of Waste Constituents

When the sources of waste constituents entering surface watercourses are enumerated, agriculture is, with increased frequency, listed as a major contributor (125, 80, 99). In general, every known constituent which may enter or be found in surface waters or groundwaters is considered to be a potential pollutant having the ability to affect the

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[1] Diffuse sources of waste constituents are characterized by the entry of constituents over a wide area.

beneficial use of water (69, p. 123). Because of the large number of substances known to mankind, these potential pollutants have been grouped several ways. Perhaps the simplest classification of waste constituents distinguishes between those that are non-degradable and those degradable by the biological, physical, and chemical processes which occur in natural waters (57, p. 14). McKee and Wolf (69) listed over 800 constituents and then subdivided this extensive listing into four categories: (1) biological pollutants, (2) radioactive substances, (3) pesticides, and (4) surface-active agents. In another classification, all these potential pollutants were classified into eight general categories by the U. S. Public Health Service (108, p. 1):

(1) sewage and other oxygen demanding wastes
(2) infectious agents
(3) plant nutrients
(4) organic chemical exotics
(5) other mineral and chemical substance
(6) sediments
(7) radioactive substances
(8) heat or temperature effects.

The waste constituents from agriculture can contribute to the first six of these eight classes which are discussed by Wadleigh (120). Furthermore, the four principal agricultural sources of waste constituents entering surface waters usually enumerated are (13, p. 5; 27, p. 51):

(1) sediment

(2) plant nutrients

(3) insecticides, herbicides, etc.

(4) animal wastes.

Since any source of waste constituents from agriculture would fall into at least one of the six classes discussed by Wadleigh, every known agricultural waste constituent should be regarded as a potential pollutant. Therefore, a comprehensive study of agriculture's effect on water quality should include each such constituent.

As this study is concerned with establishing relevant quality levels for constituents from agricultural runoff and their abatement, any such waste constituent or constituents could serve as the focus of the study. However, sediment and phosphorus are the constituents selected for intensive study. These are likely pollutant candidates for several reasons. Most obvious is the sediment that is eroded via runoff and transported into surface water supplies, which has been called the greatest single pollutant of our natural waters. Traditionally, the physical consequences and damage of sediment have received prime consideration (i.e., filling in of river channels, ponds, and reservoirs; wearing or abrasion of power turbines, pumping equipment, and other structures; and reduced recreational activities). Perhaps, more important is that the transport water that moves soil particles also transports plant residues, manure particles, dissolved solids, and any chemicals or nutrients that may be in or on the soil. The combination of environmental concern and the fact that sediment may be a carrier of other constituents has brought sediment under suspect as to its possible affect on the environment. Therefore, runoff and sediment, with their undetermined properties and loads, may be associated with a more subtle problem that has come to light in recent years. It is the problem of nutrient levels in our surface waters that permit nuisance growth of aquatic plant life. The two elements most closely associated with these growths are nitrogen and phosphorus. Of these, phosphorus has been indicated as a key nutrient and most likely to be the limiting factor for algal growth in our natural waters (121, p. 37; 114, p. 69; 22, p. 52; 92, p. 228). This assumes that sufficient amounts of the other required elements, in their appropriate forms, are present. Thus, what appears to be important in the influence of sediments on the quality of waters, in addition to the physical damage of sediment, involves the nitrogen and phosphorus relationship between sediment and water. So if the runoff and sediment from agricultural lands find their way into our water courses, both the constituents dissolved in the water and those attached to the soil are capable of movement over time and space and hence are potential pollutants of our water courses.

Another important consideration is the availability of data. There is considerable empirical data available on sediment and its transport mechanism is better understood relative to other constituents. In addition, more and more information is appearing in the literature on nitrogen and phosphorus losses from agricultural lands (121, 115, 96

123, 98, 93). Although some information is becoming available on agriculture's contribution to environmental problems, the important and difficult task remaining is that of relating its contribution to soil, climate, crop rotations, land practices, chemical and fertilizer use, and animal waste disposal practices (27, p. 51). Hence, the question arises: How would different levels and mixes of agricultural inputs and practices affect important environmental variables of concern to society?

Approaches and Processes of Managing Water Quality

Society is dependent on man's ability to work fundamental technological changes in the natural environment (39, p. 1). At first, man's attitudes and level of activities were such that the associated changes in the environment were minimal. With the continual increase in population and technology, man's activities have tended to accelerate the interchanges and interdependence between and among individuals, producing sectors and natural resources (air, land, and water). This increased production, technology, and interchange brought about greater and greater changes in the environment and a national concern for it. In the face of continued population and technological growth, what agriculture, as well as other industries, must do is move toward management systems that will maintain both high production and environmental quality (70, p. 9).

In planning such a quality management system, there are three prime alternatives:

(1) alternative objectives (i.e. quality levels)

(2) alternative methods (including technologies)

(3) institutional alternatives.

This gives rise to three fundamental issues in quality management: First, how to determine the appropriate quality level, second, what is the best means of achieving that quality level, and third, what institutions are most conducive for quality management? (57, p. 4). Since institutions and objectives are provided by society, let's assume that appropriate institutions will be provided and are dependent upon answering the first two questions. Then the prime question becomes: What is the best means of obtaining alternative quality levels? Thus, our focus has turned to management alternatives in controlling quality. Of course, a prerequisite to intelligent planning for a system is an understanding of the potential, performance, and consequences of various methods for quality control.

Using cropland runoff and water quality control as an example, let's examine the options available in the abatement and management of agricultural wastes. In general, waste reduction can be accomplished in two broad ways: (1) by reducing the generation of wastes and (2) by modifying residual wastes (57, p. 41). Furthermore, one can identify three levels or options where quality control can occur:

(1) options within agriculture

(2) options outside agriculture

(3) inter-sectoral options (joint treatment).

Within each of these options, whether it is agriculture or some other sector, there is a broad spectrum of possible methods to manage wastes. In the following sections, each option is examined for possible methods and their consequences in controlling water quality.

Options within agriculture

This option can be regarded as the control of waste constituents at their source. In general, the possible alternative means of managing wastes at their source are: (1) change in production process; (2) change in product output; (3) recovery and reuse of effluent; (4) waste treatment; (5) regulated discharge and/or dilution; (6) direct discharge into a stream; (7) other disposal means (underground or on land); and (8) quit production.

Since the control of waste constituents in agricultural runoff, in particular sediment and phosphorus, are of prime concern in this study, what are some possible alternative agricultural practices that reduce runoff, sediment, and the accompanying waste constituents? Those alternative methods that appear to be relevant are: cropping rotations, tillage and land practices, fertilizer use, pesticide use, and animal wastes practices.

It has been shown that rates of erosion and resulting sediment deliveries have been accelerated by man's use and management of land and vegetation systems (121, 93). It is also well documented that crops and crop rotations are one means of controlling sediment and its associated constituents (121, 74, 41, 103, 123). For instance, changing row crops to small grains may reduce sheet erosion from 60 to 90 per cent; converting croplands to grasslands or woodlands can reduce erosion by 90 per cent, and including meadow in a cropping sequence may reduce soil loss by 75 percent (121, p. 58). A recent report by Taylor and colleagues (93), measures nutrients in runoff from a cultivated watershed and a forested watershed at Coshocton, Ohio. Over the three-year period of analysis, the farmland yielded about 2.5 times more nitrogen and 1.5 times more phosphorus than the woodland. Moldenhauer and fellow researchers (74, p. 543) found that the 10 year average annual soil loss from corn following a year of meadow was 54 percent less than from continuous corn fertilized comparably to the rotation plots. Table 1 shows that the soil losses and associated nutrient losses were greater on southern Minnesota land in cultivated fallow or continuous corn than land in a three-year rotation containing a hay crop.

Table 1. Average soil losses and associated nutrient losses for two seasons[a]

Crop treatment	Crop	Soil loss (Tons/acre)	Nitrogen (lbs./acre)	Phosphorus (lbs./acre)
Fallow	none	7.0	56.7	0.30
Cont. corn	corn	1.8	11.5	0.10
C-O-H	corn	0.4	3.8	0.09
C-O-H	oats	0.5	4.6	0.03
C-O-H	hay	0.0	0.0	0.00

[a] Source: (41, p. 35).

This same type of information is available for tillage and land practices as a means to control sediment and its associated pollutants. For instance, cropland terraces may reduce soil erosion by 75 percent, and in combination with crop and tillage, practices can reduce soil losses to practically nothing (121, p. 58). In a recent publication, Gard (36, p. 5) reports that soil losses for the double-cropping period, October 28, 1968 to November 10, 1969, were ten times as great for conventional till plots on the 9 percent slope and six times as much on the 5 percent slope as for no-till plots. The results of Weidner et al. (123, p. 383) indicate the effect that soil management and tillage practices can have on the amounts of nutrients carried in runoff water. Under improved management, nitrogen in runoff is reduced by about 63 percent and phosphorus by 70 percent. The improved practices involved contour tillage, liming, and increased fertilization.

The above findings document the importance of land and vegetative systems in controlling runoff, sediment, and the associated plant nutrients. However, those practices receiving the most attention at present are fertilizer use, pesticide use, and animal wastes. This increased attention is the result of increased use of fertilizers and pesticides, concentration of livestock production units, and the associated environmental problems of increased nutrient levels in our water supplies and pesticide levels in fish and wildlife.

The possible association of these environmental problems with fertilizer and pesticide use has brought about proposals to control the use of fertilizers and pesticides. Such controls consider only the amount of an element applied, but the timing of application or the type or form of the element may also be of considerable importance. Furthermore, a recent study by Mayer and Hargrove (67) indicates that there is a wide range of substitution between fertilizer use and crop acreage. Thus fertilizer restriction may increase land needs, exposing more land to erosion and the accompanying loss of nutrients. Perhaps it would be better to increase fertilizer on the better land enabling the poorer land to be retired to grasslands or woodlands. The problem is that available data do not permit making valid estimates of nutrient transfer from fertilization practices to water supplies. Therefore, the impact of a restriction on fertilizer on water quality depends on a better understanding of the behavior of nitrogen and phosphorus applied to the soils under alternative practices.

It is apparent that the concentration and amount of sediment and nutrients in runoff from agriculture result from interaction of many factors. If appropriate control means are to be adopted by agriculture, it is imperative that agriculture develop a better understanding between control methods and the physical, chemical, and biological processes to determine their effect on the environmental parameters being considered. In addition, the costs associated with these quality control methods within agriculture need to be determined.

Options outside agriculture

To obtain the best means (least cost means) of managing water quality between agriculture and other uses, the options available to these other uses must be considered also. For instance, assuming agricultural wastes have adverse effects on subsequent uses, in addition to the options in agriculture, these uses have the options of (1) treating wastes prior to use, (2) changing their production process, (3) locating a new water supply, (4) relocating their place of production, (5) modifying or changing products, or quit producing.

Here again, the effectiveness (performance) of these options with respect to the environment parameters being considered and their costs must be determined. Then the comparison of the effectiveness and cost of alternative means both within and outside agriculture may lead to the least cost system of managing water quality. However, this system may not only be derived from agricultural or nonagricultural practices, but from joint management, which can be regarded as intersectoral options.

The point to realize is that in a strategy for managing water quality, there is no single solution for the problem, only a combination of methods can succeed.

CHAPTER III. NATURE AND DIMENSIONS OF THE SEDIMENT AND PHOSPHORUS PROBLEM IN MANAGING WATER QUALITY

The limited natural resources, including air, soil, and water, must not only support a society in which population and industrialization are increasing but must also assimilate the ever-expanding variety and volume of waste materials rejected by society. Utilization of natural resources and the related waste disposal problem may generally be regarded as a function of man's knowledge. Through his increasing knowledge of these resources and the relationship between utilization and associated waste disposal problems, man is continually transforming and using the resources he comes in contact with to better satisfy his wants. This suggests quality aspects must be viewed as a total system that embrace man and his environment, for the problem of waste disposal in general is an element in the larger problem of environmental quality control and resource allocation. Thus, man's utilization of resources gives rise to cause-and-effect relationships between resource use, disposal of used resources, and environmental quality which in turn raise important physical, institutional, and economic questions. The scope and magnitude of these problems require a unified approach that involves consideration of three interlocking dimensions. Specifically, the relevant dimensions of the problem encompass (1) physical (hydrologic, biologic, technological) relationships, (2) economic analysis, and (3) institutional forms (85, p. 13). To recognize and consider this three-fold framework of quality management lies at the very heart of any process or efforts to analyze, understand, and remedy quality problems.

Scope of Water Quality Research

The concept of water quality management embraces a three-fold framework within which water quality problems can be analyzed.[1] In the process of analyzing water quality problems and forming water quality policy, we derive the basic elements of what is physically possible, economically feasible, and institutionally permissible from the three dimensions in an integral manner.

The physical dimension is concerned with what is technologically possible. Physical and biological sciences provide use with the range of physical possibilities and the probabilities of consequences attached to particular water uses and their quality control measures. Too often in the past, physical systems have been designed to achieve exacting production efficiencies, neglecting to consider their possible implications on other goals (10, p. 14). It is also the function of physical and biological sciences to expand the possible alternatives available through research discoveries, which is necessary for continued progress. However, technology without the economic consequences of particular alternatives does not permit us to make decisions. Timmons and Dougal (106, p. 668) stated the relationship between advanced technologies and the selection of them as follows:

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[1] The concept of a three-dimensional framework for analyzing water resource problems is attributed to Dr. John F. Timmons. Although this may be partly repetitive, I feel this approach to quality problems needs to be stressed and is absolutely necessary if the results are to lead to decisions which insure relevant water qualities.

> Although the continual expansion of physical possibilities is necessary for continued economic progress, technology in and by itself does not permit choice nor does it reveal the economic consequences of particular choices. The range of choice is broadened through physical studies, but the making of decisions by individuals and by public entities necessitates inquiries into the economic dimension which is responsible for revealing which physical or technical possibilities are economically feasible.

With respect to water quality, Timmons (101, p. 37) has stated: ". . . the economic dimension is necessary in making decisions about (1) the level of water quality and (2) the technological means for achieving particular water quality changes." Thus, in making decisions between the range of alternatives available, economic analysis is needed to reveal the costs and benefits of alternative solutions (i.e., their economic feasibility). The economic analysis is necessarily founded upon the best available physical and technological coefficients, for without these the economic analysis would at best be meaningless if not incorrect. The relationship between economic and physical research has been stated by Crutchfield (23, p. 137):

> Economic research is no substitute for research in the physical and engineering fields, but rather builds on them and serves to point up, in some cases dramatically, the gaps in our knowledge of the physical determinants of water quality and the physical effects of varying degrees of degradation of water quality.

The above points out the need for solutions to be based on a wide range of possible alternatives, their consequences, and costs. Furthermore, proposed solutions failing to consider alternatives but rather based solely on "physical requirements" may be needlessly costly.

Velz et al. (113, p. 123) has pointed out the insufficient attention being given to a broad range of solutions to the water quality problem. There seems to be a misconception that the only approach to water quality control is through waste treatment to reduce discharge to the stream, ignoring completely other important elements such as stream flow, flow augmentation, storage, etc. This is also exhibited by the tendency for planners, be they physical or social scientists, to gear their solutions to the approach they are familiar with. For example, in solving water supply problems, they have typically begun looking for additional supplies and paid less attention to the possibilities of reducing consumption, reusing waste water, abating pollution of streams, or changing human habit and preference. Part of the problem lies in a certain amount of technological myopia and part in the tendency to regard institutions as given.

Davis (24, p. 8) suggests that even if the inadequacies of technological and economic analysis were assumed away, it is unlikely that a wide range of alternatives would be considered because of existing institutional complexities. Under existing structures, the domain of particular agencies is limited and certain alternatives are favored politically which tend to limit the alternatives considered. For example, the U.S. Army Corps of Engineers may involve itself in low-flow augmentation for multi-purpose reservoirs but is not authorized to consider treatment plants. Also, a fundamental weakness of existing legislation (i.e., federal assistance to reservoirs for flow augmentation and municipal treatment plants) concerns almost entirely the abatement of pollutants after they are produced, making them more appealing than methods directed toward preventing or reducing the production of wastes. This is also exhibited in depletion allowances and capital gains advantages which favor use of raw materials over reuse and recycling of used resources.

The obvious conclusion is that existing institutions (structures) may either inhibit or facilitate the achievement of water quality controls which prove to be physically possible and economically feasible. Thus, to free physical and economic analysis of existing structures, it is important to regard them as variables, thereby facilitating true exploration into the means of controlling water quality.

Therefore, use of this three-dimensional framework can provide management programs and aid future analysis in pointing out three broad classes of information needed (24, p. 131):

(1) Physical and biological alternatives and consequences of each action with regard to quality influences

(2) Consequences for human welfare (value) of alternative courses of action

(3) Estimated response to alternative institutional arrangements for influencing people, agencies, and their action with regard to quality.

This approach and view also offers hope in that with adequate technology, economic analysis, and proper institutional forms, it may be possible to provide the knowledge and understanding needed to resolve the problems inherent in the production, management, and control of pollutants.

Furthermore, the integrated approach suggested and the complexity of data needs point out the necessity of multidisciplinary research teams in resolving these problems.

Each of the three dimensions and multidisciplinary research are discussed in the following sections.

Physical Dimension

This section concentrates on the movement of sediment and phosphorus into watercourses from agricultural lands and their impacts and control. Since hydrologic, agronomic, and biological relationships underlie these considerations (i.e., soil erosion, its transport and its impact), data needs and that available from these disciplines are discussed.

Sediment and phosphorus as pollutants: magnitude and impact

To regard sediment and phosphorus from agricultural lands as pollutants requires, first, a means of transporting these elements to the water supply, and second, they are in amounts sufficient to adversely affect other uses. The literature documents both the magnitude of these elements and their impact.

Sediment from soil erosion entering our watercourses through surface runoff is estimated at four billion tons annually, the equivalent of about 4 million acres of topsoil (121, p. 24). About three-quarters of the sediment comes from cropland where water erosion is the dominant problem on 179 million acres of cropland and a serious problem on an additional 50 million acres (55, p. 52). This sediment entering our streams has a bilateral effect. It not only impairs the quality of the receiving waters but depletes the land resources from which it is eroded at the same time.

The sediment load in our streams originates from many sources through the erosion process. On agricultural and forested land, it arises primarily from cultivated land, burned-over forest land, logging roads, and over-grazed range and forest lands. Activities outside agriculture which contribute considerable quantities of sediment are suburban development projects, industrial construction, highway construction, and strip mining operations. In addition, there is the sediment from stream bank erosion and geologic erosion of such areas as the Badlands of South Dakota (55, p. 52) which can be regarded as "natural erosion."

The adverse effects of these sediment loads are extremely diverse, but can be divided into direct and indirect (secondary) impacts. The direct impacts are the most obvious, which is the filling in of stream channels, lakes, reservoirs, and farm ponds. Sediment has also caused serious abrasion of turbine blades in power generating plants. However, the secondary effects may be more important, for they represent a wide range of physical and biological implications. As the sediment load in surface waters increases, the expense of clarifying it for public, industrial, or sprinkler irrigation use increases. Since people desire clean water for esthetic and recreational purposes, esthetics and recreation values vary inversely with the turbidity of lakes and streams.

Suspended sediment affects the dissolved oxygen level of streams and reduces light penetration, thereby affecting its assimilation capacity and fish productivity (121, p. 24; 69, p. 290). Fish and aquatic life are also reduced by sediment blanketing of spawning nests and food supplies.

However, the biological impact of sediment arises in the main from the material transported with and by sediment. Of particular concern here is the plant nutrients in agricultural runoff and their relation to the problem of eutrophication.[1] It is estimated that 50 million tons of primary nutrients are lost from agricultural and forested land annually via the sediment delivered to our streams (121, p. 24).

Although several plant nutrients and trace elements are required for plant growth, the literature points out that phosphorus is the nutrient most likely to be limiting in our natural waters.[2] This view is supported in that harmful algae growths are best controlled by limiting inflow of phosphates because (97, p. 33):

(1) It is present only in traces in oligotrophic lakes.

(2) Natural tributaries entering lakes contain very little phosphate if not subject to wastes from man's activities.

(3) Fewer phosphates than nitrogenous compounds are washed off agricultural lands.

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[1] Eutrophication is a natural process whereby lakes become shallower and nutrients build up leading to increased productivity and eventually nuisance plant growths. Man's activities tend to accelerate this process.

[2] See Chapter II, p. 22.

(4) Bacteria and blue-green algae living in lake water are able to bind gaseous nitrogen organically.

(5) Nitrogenous return in larger quantities than phosphate compounds from dead organisms and sludge.

Using Wadleigh's estimates (121, p. 24), about two million tons of phosphorus are delivered to our surface waters yearly, either in or attached to sediment. Verduin (114, p. 65) presents data which indicate that phosphorus levels in all the major streams of the United States are five to thirty times higher than those observed in streams of forested areas, i.e., "natural level." In addition, his comparison of phosphorus concentrations in streams whose watersheds represent agricultural land with that in streams whose watersheds also includes urban areas suggests approximately one-third of the phosphorus contribution may come from agriculture.

If other nutrients are generally present in sufficient quantity to permit algal blooms, then this movement of phosphorus into streams, lakes, and reservoirs may stimulate the growth of unwanted algae. The excessive growth of algae and other aquatic plants results in serious oxygen depletion when the plants die and decay. The resulting low levels of oxygen can and have resulted in fish kills. They are also responsible for foul tastes and odors in drinking water, clogging of water intake filters, and interfere or detract from recreational uses.

Distinctly, sediment and phosphorus are of major consequence on water quality and the environment, affecting many uses of water. However, the extent of agriculture's role in the concentration and impact of phosphorus in surface waters remains to be determined.

Predicting soil and phosphorus losses

Surface runoff from agriculture land is the primary transport agent of sediment entering our surface waters. Planning for the control of sediment requires knowledge of the relations between those factors that cause loss of soil and those that help reduce such losses on cropland. Toward this end, the "universal soil-loss equation"[1] was developed to provide specific guidelines needed to help select appropriate control practices for particular farms or fields. The application of this equation gives long term (25 years or more) average annual soil erosion losses caused by rainfall (128, p. 41). In predicting these losses from individual fields, the equation takes into consideration rainfall intensity and duration, soil type, slope length and gradient, cropping practice and erosion-control practices. Results reported from recent studies applying this equation (54, pp. 6-7) show close agreement between measured and predicted erosion, demonstrating that this approach is sound. However, the prediction of soil erosion losses for individual storms or for a specific year are not as accurate (128, pp. 39-40).

Estimation of sediment losses from watersheds is even less reliable because the complex soils, land use patterns, and topography present problems in interpretation and factor evaluation that require further research. However, by breaking the drainage area into a series of relatively homogenous land tracts, such as land capability classes,

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[1] This equation is presented in Wischmeier and Smith (128, p. 3).

the erosion equation provides a methodical means of bringing the effects of rainfall, soils, and land use into the computation of sediment losses by sheet and rill erosion. An additional problem is that the above are gross-estimates of the quantity of soil moved from its original position. Being interested in only that portion of sediment actually entering the watercourse, the initial sediment loss estimates must be adjusted for that portion deposited in terrace channels, sod waterways, etc. The impact of these factors on the gross-erosion estimates have not been evaluated (128, p. 43). Therefore, to predict sediment yield, i.e., that portion delivered to the stream, a delivery ratio[1] is needed.

In attempting to determine sediment delivery ratios, some studies have tried to correlate the delivery ratio with drainage area. Generally, an inverse relationship is posited.[2] While Maner (65) found a significant relationship between delivery ratio and drainage area in the Blackland Prairie area of Texas, Beer et al. (8) conclude there is no relationship between delivery ratio and drainage area for the loess soil area of Western Iowa. However, Seay (85, p. 75) by comparing estimated total annual sediment production for the Nishnabotna Basin with suspended sediment loads in the river arrived at deliver ratio of 25 percent. Since the Nishnabotna is also being used in this study, that value, plus 20 and 30 percent, will be used.

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[1] Delivery ratio is the percentage of the total soil lost from the area that is delivered to a specific point.

[2] Johnson and Moldenhauer (54, p. 11) present data collected by Gottschalk (37) which supports this.

While using the "universal soil loss equation" and "delivery ratio" will give estimates of sediment being delivered to the watercourse under different cropping and land practices, nothing similar to this exists for predicting phosphorus losses in agricultural runoff. Moreover, a review of the literature on phosphorus losses from agricultural lands is not very encouraging. But to expect something other than varied results from studies carried out over a short time period and under different soil types and cultural practices is not realistic. However, the literature does point out a positive relationship between erosion and phosphorus losses.[1] Thomas et al. (96, p. 679) in a detailed analysis of soil and nutrient loss found a linear relation between erosion and nutrient losses. Weidner et al. (123, p. 382) also reports a good correlation between total solids in agricultural runoff and phosphate losses. It is also generally agreed that phosphorus is readily absorbed by soil particles and becomes relatively immobile, and this is supported by the low phosphorus content found in most groundwaters (11, p. 75). Schuman concluded (84, p. 3 ". . . since phosphorus is relatively immobile in soil, phosphorus loss from agricultural lands occurs primarily from phosphorus absorbed on eroded soil transported by runoff."

In addition, the literature on soil erosion establishes the fact that erosion is selective. It has been observed that the eroded soil

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[1] This can be seen by a brief look at Table 1, p. 26 .

generally contains a higher concentration of silt and clay, organic matter, and plant nutrients than the soil from which it was eroded. This selective removal of constituents by erosion has been termed "fertility erosion" (66, p. 543). Massey et al. (66, p. 354) report average enrichment ratios[1] of 2.7 for nitrogen and 3.4 for phosphorus. Stoltenberg and White (90b, p. 407) report that the nitrogen and phosphorus content of eroded material was almost double that in surface soil.

Considering the above properties of phosphorus and selectivity of erosion, estimates of phosphorus losses will be obtained by applying the level of phosphorus in the surface soil and an enrichment ratio to the sediment losses predicted by the universal soil loss equation and the delivery ratio. In this manner, estimates of both sediment and phosphorus losses will be obtained under various cropping and erosion-control practices. Because of the relationship between phosphorus and sediment, the agricultural practices which will tend to reduce both constituents are sound soil conservation practices.[2]

Transport mechanism

In linking these constituents with the point of water use, it is necessary to describe the transport of sediment and phosphorus by the watercourse. Johnson and Moldenhauer (54, pp. 15-17) and Seay (85,

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[1] The enrichment ratio is the increase in the content of constituents in the eroded soil over that in the original surface soil.

[2] Possible control practices were presented in Chapter II, pp. 24-25.

pp. 19-24) provide a review of the literature on sediment transport. They conclude that most of the work is empirically based and that considerable study is needed to provide a general approach to the mechanics of sediment transport. Robinson reaches the same conclusion, stating ". . . despite decades of study, the mechanics of sediment transport are not well known" (82, p. 19). However, Johnson and Moldenhauer (54, p. 15) indicate that in Iowa, probably more than 85 percent of transported sediment is in suspension and 90 percent or more of the particles are in the clay and silt range. Since most material in transport is in suspension, suspended sediment will be regarded as a measure of the total sediment load of the river.

The transport of phosphorus by watercourses is even more complex and less understood. Studies indicate that upon entering a flowing stream, it is taken up physically, assimilated biologically or in essence removed from the flowing water mass (56, p. 377). Therefore, equilibrium reactions involving sediment, phosphorus, water, and aquatic plants are influenced by physical, biological, and chemical factors, making this system extremely difficult to study.

The literature review provided no insight into the movement and rate of release or absorption of phosphorus in natural waters. One can only conclude that considerably research is needed to isolate and examine physical, biological, and chemical factors that influence the movement and availability of agricultural phosphorus in surface waters. While the complex reactions of phosphorus in surface waters is not understood, it is pointed out in the literature that there appears to be a positive relationship between solution (available) phosphorus and sediment phosphorus (84, p. 2; 76, p. 224). It is generally thought that while the total phosphorus loss from agriculture may be relatively large, only a small portion, probably not over 5 to 10 percent, will be in the available form at one time (56, p. 378; 89, p. 17; 121, p. 7). However, analysis of sediment and available phosphorus in two Iowa studies indicate that this ratio or percent changes with the sediment concentration. Schuman et al. (84) found the following relationship between sediment and solution phosphorus:

$$Y = -0.39 + 21.13X$$

where:

Y = sediment phosphorus

X = solution phosphorus.

This results in a solution to sediment phosphorus ratio of just under five percent. These results were obtained from samples taken during runoff periods when sediment concentration where high, i.e., frequently in the 10,000 to 15,000 ppm range.[1] A similar analysis of the Des Moines River between Boone and Des Moines, Iowa, indicates a ratio of solution to sediment phosphorus is between .25 to .33.[2] The samples in this study were taken at periods of low flow with sediment concentration between 100 and 200 ppm. The above suggests the sediment acts as a

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[1] Data on sediment concentration is from 1969 Annual Research Report on the Treynor experimental watersheds in Western Iowa, a joint study of U.S.D.A., A.R.S., SWCRD, Columbia, Missouri, and the Agronomy Departments at Iowa State University and University of Nebraska.

[2] Information obtained from E. R. Baumann. Personal communication. June, 1971.

buffer system for solution phosphorus in the stream system. This type of a relationship is also indicated by Holt et al. (42, pp. 31-32), suggesting the sediment appears to have a leveling influence on phosphorus concentrations in our surface waters. Thus, it appears that the available to sediment phosphorus ratio is inversely related to the sediment concentration. Since it is the available phosphorus, which occurs mainly as orthophosphate, that is of prime concern in stimulating algal growth, ratios relating available to sediment phosphorus for various sediment concentrations will be used. This will allow the prediction of available phosphorus from the predicted phosphorus losses, which was explained earlier. Furthermore, in using this approach, it is assumed that the estimated phosphorus in and on sediment losses is a measure of total phosphorus. Since over 85% of the sediment load is in suspension in Iowa streams and the majority of phosphorus is tied up in sediment, this assumption does not appear to deviate that much from reality.

In summary, the sediment and phosphorus losses from agricultural land are potential pollutants of our watercourses. Means for estimating the soil and accompanying phosphorus carried off land via rainfall erosion and by the watercourse exist, although a few simplifying assumptions are needed. Finally, a broad range of options and means of managing sediment and phosphorus are available.

Economic Dimension

The physical section provides information which allows for the selection of those control means which maximize removal. However, as long as abatement methods have positive costs, the analysis must determine the economic feasibility of the means physically possible.

Market system and water quality management

Economists have only recently begun to concentrate on the economic problems of water quality management. The economics of waste disposal is but one aspect of the primary concern of economic analysis, which is the allocation of scarce resources among competing ends so as to maximize net benefits to society. Therefore, in order to recognize and to effectively alleviate the problems presented by water quality management, it is essential to have a concept of the market system. The model, which best provides an understanding of its basic functioning and a benchmark to measure its performance against, is the economist's model of perfectly competitive markets. It has been shown that this model, under certain highly restrictive conditions, will lead to an allocation and use of resources which will maximize welfare.[1]

Under a competitive market economy, each firm and individual, acting independently, attempt to allocate their resources so as to maximize net benefits. There is a common element running through all decision problems expressible by the simple question, "Is it worthwhile?" (4, p. 21), which can be determined by marginal analysis. Specifically, economic theory tells us that each firm or individual, considering all benefits and costs, should use a resource up to the point where the additional (marginal) cost of another unit equals its additional value

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[1] For a presentation of the welfare maximization aspects under perfect competition, see, e.g., Ferguson (33, pp. 373-390) or Koopmans (60, pp. 41-96).

product. Looking at Figure 1, an explanation of the relevance of marginal analysis with respect to water quality control is possible.[1] The line A-B indicates the additional cost, using optimum abatement techniques, of improving water quality by one unit. C-D represents the additional damages avoided (benefits) to subsequent water uses from the unit improvement in water quality. Taking point E, one observes that the incremental benefits exceed the incremental costs. As long as this is true, total benefits can be increased by continuing to improve water quality. Observing point G, it becomes apparent that incremental costs are greater than incremental benefits. Under these circumstances, total benefit would be increased by reducing the level of water quality to be maintained. This would indicate that water quality control should be extended to the point where the incremental cost of abatement is equal to the incremental damages avoided, i.e., point F on Figure 1. Moreover, as indicated above, the private maximization of benefits would also lead to maximum public welfare under a competitive market system.

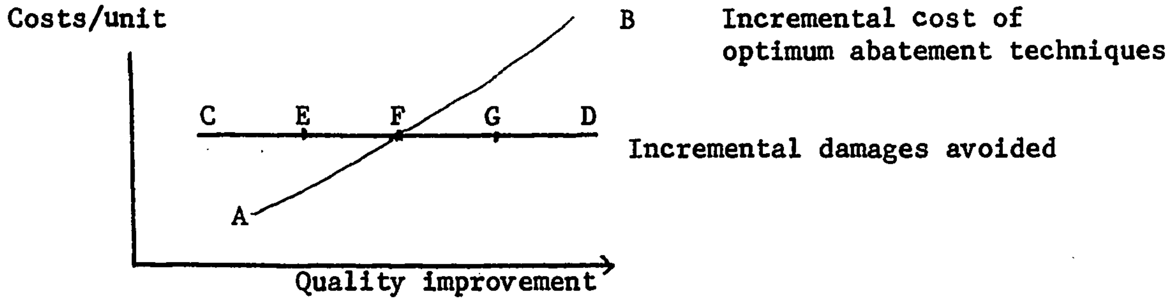

Figure 1. Optimum water quality

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[1] Kneese provides a similar presentation of the market system and water quality control (57, Chapter 5).

Like most models, this is a simplification of reality and seldom does our economic system function according to the criteria specified above. This is particularly true of problems associated with water allocation and water quality control, for water has generally been regarded as a free good and has not been subject to the market system. There appears to be three fundamental problems which tend to prevent the market system from operating in an optimal manner. These problems may be defined in terms of (1) external diseconomies, (2) external economies, and (3) measurement of benefits and costs. Each of these problems will be discussed in terms of their impact on resource allocation and possible solutions to alleviate them. Finally, the joint nature of these problems and their implication for institutional intervention are discussed.

Before continuing, it may be helpful to discuss the general nature of externalities and their implication. This seems particularly relevant in view of the increasing attention they are receiving and the growing pressure to include them in decision processes. Mishan (71, p. 182) states, ". . . the attention given to external effects in recent literature is, I think, fully justified by the unfortunate albeit inescapable fact that as societies grow in material wealth, the incidence of these effects grow rapidly." This view is supported by Kneese and d'Arge (58) who suggest that externalities are inherent in the interrelationships between production, consumption, and the environment in highly developed economies.

An important aspect of the nature of externalities with respect to quality control problems results from the above. It is that external effects are not an isolated, exceptional kind of issue, but rather are part of our production and consumption processes and their effect on the environment. Moreover, these external effects tend to increase with increased economic activity or societal wealth. To consider these effects in our decisions necessitates an understanding of the nature of externalities and their impact on the market system.

An external effect is commonly defined as the response of firm or individual action to the activity of others. Buchanan states (15, p. 408), ". . . an externality is present when an activity on the part of one person (his production or his consumption of some good or service) affects the utility or cost function of a second person." This definition emphasizes the interdependence of production or utility functions, but is unsatisfactory in that this also holds where externalities are absent. For example, the Walrasian general equilibrium is an interdependent system and an exogenous change in the behavior of individuals can lead to a change in the equilibrium set of products and prices, thereby affecting the output and utility of others. However, there is an important distinction between the interdependence of utility or production functions that must be recognized (72, p. 2). In the case of the general equilibrium (interdependence) system, the influence on utility and production functions of others is exerted indirectly via the relative prices and in the presence of perfect competition the resulting solutions are Pareto optimal. In the presence of externalities, the influence upon utility and production functions of others is exerted directly via an argument in the utility or production function. Thus, the presence of external effects violates the criteria specified for the equation of Pareto optimality with the perfectly competitive market model and may lead to what has been termed "market failure" (3).[1] The importance of this is that the perfectly competitive market system is unable to deal with external effects.

Realizing that external effects are widely distributed and that their possible impact on optimal resource allocation (public welfare) may be substantial, the question arises as to when externalities are relevant to decision-making and to what extent their impacts should be corrected. Perhaps Buchanan and Stubblebine (16), in attempting to provide operational definitions of externalities, answer the above question. They begin with the common definition of externalities and then differentiate among various types of externalities. It is their differentiation of potentially relevant externalities and Pareto-relevant externalities that provides the needed information with respect to relevant externalities and their appropriate level of improvement. They state that a potentially relevant externality exists ". . . when the activity, to the extent that it is actually performed, generates any desire on the part of the externally benefited (damaged) party to modify the behavior of the party empowered to take action through trade, persuasion, compromise, agreement, convention, collective action, etc." (16, pp. 373-374). Conversely, if the externality presents no such influence,

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[1] For an elaboration of types of externalities which may lead to market failure, see Bator (3 , pp. 363-371).

it is defined as irrelevant even though the externality still remains. They then define an externality as Pareto-relevant ". . . when the extent of the activity may be modified in such a way that the externally affected party can be made better off without the acting party being made worse off" (16, p. 374). This means that Pareto-relevant externalities are characterized by gains from trade. Therefore, the external effects should be reduced so long as the value of the damages avoided by the affected party exceeds the cost to the creator of reducing it. Where the opposite is true, the reduction of externalities will not take place. Thus, as Buchanan and Stubblebine point out, only Pareto-relevant externalities are eliminated at the Pareto-optimal solution. The importance of this is that the existence of externalities establishes the potential but not the fact that institutional intervention will result in an improvement over the market situation.

Having a general understanding of the nature and relevance of externalities in quality problems, let us turn to the importance of externality and measurement problems in water quality management. The discussion which follows considers the simple case of an upstream user who discharges waste constituents in the stream which affects subsequent uses downstream. It is assumed that the external effects are Pareto-relevant and therefore remedial action is economically feasible. The impact of Pareto-relevant external economies and diseconomies on water quality management are discussed in the next two sections.

External diseconomies

Water pollutants exhibit important economic characteristics in that their costs are dissociated from benefits. This dissociation of costs from benefits means that the costs of a particular course of action (discharging wastes into a stream) are borne by an economic decision unit which is managerially independent of the unit carrying out the action. This type of dissociation gives rise to what are more generally known as external diseconomies. They frequently arise among water users in that water provides a physical linkage between uses and thereby allowing part of the costs of one use to be shifted to alternative uses. Because of these external diseconomies, problems arise when the costs associated with the water pollutants of one use are shifted to other uses in a spatial or temporal incidence. These external diseconomies tend to make other uses more expensive and may even force them out of the market. Dr. Kneese states (57, p. 80) ". . . a society that allows waste discharges to neglect the offsite costs of waste disposal will not only devote too few resources to the treatment of waste but will also produce too much waste in view of the damage it causes." This is simply another way of stating that the external diseconomies are Pareto-relevant, thereby providing a rational for private interaction or public intervention in water quality decisions.

The above suggests that water pollution is essentially a problem of external diseconomies. Mishan (72, pp. 14-16) presents and discusses five common methods suggested for correcting outputs for external diseconomies. These methods are: (1) voluntary agreements, (2) outright prohibition, (3) regulation, (4) tax/subsidy solution, and (5) preventive devices. There are three core problems that run through each of these solutions. The first is the problem and cost of obtaining sufficient information to negotiate and implement optimal water quality solutions. The second problem, which is directly related to the first one, is that of estimating costs and benefits associated with various levels of water quality. The third problem is the nature of the abatement of water pollutants which is discussed next.

External economies

The abatement of water pollutants exhibits important economic characteristics in that benefits are dissociated from the costs. In this case the upstream investor in water quality may not be able to capture the benefits occurring to downstream users, thereby giving rise to external economies. Moreover, the inability of the investor to capture the benefits of quality improvement gives him no incentive to make the investment. However, he may be compensated by other users who benefit from his investment, but the prospects for such an agreement diminishes as more and more parties become involved. The problem is that the production of improved water quality is likely to benefit a number of downstream users and is equally available to each user. These characteristics of water quality improvement are similar to Samuelson's (83, p. 387) definition of a public good, i.e., ". . . each individual's consumption of such a good leads to no subtraction from any other individual's consumption of that good." Thus, water quality improvement takes on the characteristics of a public good. Hence, as

Samuelson (83) points out, consumers have no incentive to reveal their true preferences. This means that ascertaining benefits from public goods for comparison with benefits foregone by devoting resources used in their production to some alternative use is extremely difficult. Thus, the prime problem here is that of the public nature of water quality changes.

Measurement of benefits and costs from external effects

In addition to and intertwined with the problem of externalities is that of measuring the benefits and costs of water quality changes. Perhaps, the most difficult problem here is the measurement of benefits from improved water quality. For example, what is the benefit of a unit of water quality to esthetic, recreation, and/or fishing. Our inability to value such benefits points out the need for better techniques to value these difficult-to-value benefits.

Because of the difficulties in measuring benefits of improved water quality, attention has been directed toward the least-cost alternatives of enhancing water quality. Here the minimum cost (i.e., opportunity cost of diminished or foregone uses) of managing for selected levels of water quality criteria are determined, which is the approach used in this study. These least-cost values automatically place a minimum value on the management of water quality for the selected criteria. Moreover, if all the relevant alternatives are considered[1] and

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[1] The alternative methods for water quality management are presented in Chapter II, pp. 16-22.

to the extent that treatment costs of downstream users are representative of their benefits from changes in water quality, the resultant quality level would tend to approach an optimum where incremental benefits equal incremental costs. Thus, the level of water quality would be determined by the comparison of incremental benefits with incremental costs.

Problem of intervention

In view of the externalities and measurement problems associated with water quality management, the possibility of a market solution seems highly unlikely. This is further supported by the fact that usually a large number of individuals are involved, thereby increasing the transaction costs and decreasing the possibility of voluntary action. However, even with the inability of the market system to maximize benefits from water quality, the limit on water quality improvement remains essentially an economic one. This is true for the controlling question will remain as Kneese points out, (57, p. 71), ". . . how much of our resources are we willing to devote to maintaining and improving water quality?" But in view of the problems discussed above, it is likely that the answer to this question will be through public intervention.

In summary, the perfectly competitive market system usually is inadequate to deal with external effects. But the mere presence of externalities does not necessarily suggest that public intervention is always needed. However, the public nature of water quality and the difficulty in measuring benefits from water quality changes severely hinder the possibility of a market solution. Thus, efforts to increase our benefits from water quality management are likely to involve institutions or structures. The role of institutions in water quality management is the topic of the next section.

Institutional Dimension

The institutional dimension is made up of laws, customs, organization structures and other group controls over human behavior (106, p. 668). They provide use with the "rules of the game" in that they determine if it is possible to put into effect measures which meet the physical and economic tests. This simply means that institutional arrangements are used for implementing water quality management systems. Thus, at a particular time and problematic situation, these structures can either inhibit or facilitate the attainment of the desired water quality criteria. It is important then to regard structures as variables, thereby allowing them to change to facilitate the development of improved management systems.

Viewed in this manner, the importance of analyzing institutions can be seen. Yet, in many economic studies, the institutions are taken as given (invariable). Ciriacy-Wantrup (19, p. 40) states ". . . in economics social institutions have been pushed into the background in recent decades in favor of optimizing models." The lack of institutional analysis seems to be indicated in the suggestion that although the many technological problems of pollution are complex and challenging, their solution may be less difficult than those associated with public policy and institutional patterns (75, p. 15). This view is also supported by Kneese and Bower (57, p. 255), who state:

> Little is known about how to devise legal and institutional arrangements that will permit efficient and politically responsible implementation of water quality management programs. Compared with engineering and even economic studies, institutional studies of water quality management are in their infancy.

It appears that in suggesting the transition from a competitive free enterprise system to a mixed public-private system, we have failed to consider one vital point. That is what are the criteria of such a water quality management system that will tend to increase our satisfaction from the use of water. For a water quality management system to improve our satisfaction from water above that obtained under the free market system, it must provide extensive information and knowledge of physical and economic relationships to implement an improved system.

Thus the need arises for a set of criteria whereby we can evaluate various institutional arrangements in terms of their adequacy to deal with complex problems of water quality control. Seay (85, p. 38) upon review of the literature suggested five such criteria:

1. The water management entity should encompass the major supply and use areas, and thus account for major interactions.

2. The water management entity should be of sufficient size to (a) provide an adequate financial base, and (b) take advantage of any scale economies in waste treatment or water supply systems.

3. The water management agency should have a wide range of water quality improvement techniques available to it.

4. Water quality should be managed jointly with water quantity and the relevant associated land areas.

5. Values representing the preferences of supply areas, use areas, and political entities should be determined and expressed in water management decisions.

The development of institutional arrangements to fulfill these criteria should allow us to demonstrate the nature of the gains to be realized from expanding the analysis of alternatives in water resource planning process. Davis (24, pp. 119-120) suggests some possible productive dimensions of an expanded analysis:

1. To extend the analysis to more than one set of objectives so that we can at least begin to ask some questions about the willingness to pay for results.

2. To extend the analysis to payoffs from possible changes in technology, because technology to a large extent is controlled by the direction and magnitude of research effort and because adaptability over time in a system may be a means to efficient system design.

3. To extend the analysis to possibilities which may be precluded by current institutional arrangements, in order to know something of the gain derived from rearranging institutions bearing on the design and operation of water quality management systems.

Strangely enough, it seems that the above suggestions for possible means for increasing the benefits from water quality management incorporate the economic, physical, and structural dimensions of the problem.

In summary, to achieve increased benefits from water quality management, requires that the three dimensions of water quality problems be dealt with effectively. First, we must continue to advance our technology of water management and use so that the increased demands on water resources can be met at a minimum increase in cost. Second, a public consensus on the costs and benefits from alternatives in the management and use of water needs to be established, so the kinds of water systems that will best serve the public can be developed. Third, is the development of structures that will facilitate the best use of water. The question remains as to how to approach this three-dimensional problem, which is discussed in the next section.

Multidisciplinary Approach

From the preceding discussion on the vast and complex data and knowledge required to deal with the three dimensions of water quality management, it is obvious that no one scientific discipline can deal with the problem effectively. The analysis, development, and maintenance of a water quality management system is highly involved and requires legal, medical, technological, biological, economic, social, esthetic and political considerations. There is a general recognition that the complex and dynamic nature of the quality problems requires effective multiple discipline attack (90a, p. 3). This is also supported by Kneese and d'Arge (58, p. 101) who suggest a need to move rapidly toward a fuller understanding of economics, politics, and technology of environmental management and that the best approach would be a multidisciplinary research project to analyze material flows as related to the economic structure of a particular region.

Furthermore, it is important that these multidisciplinary projects be fully integrated rather than what Timmons has characterized as a "layering of knowledge" (102). In the past, interdisciplinary research has been mainly on a person-to-person basis to deal with technological details of a particular problem. What is needed is a model for conducting research by teams of scientists involving several disciplines. Stanley (90a, p. 5) presents such a model which he likens to a matrix organization. In such an organization, each person has simultaneous relationships with persons in his own discipline and with persons in different disciplines, which comprise a project team. Thus, this is merely an extension of the department system where each individual is a member of a department and a member on one or more project teams. These project teams would then carry out fully integrated research on problems of mutual interest. This appears to be the approach of future research and the one this author will be involved in at least for the next few years.

CHAPTER IV. DEVELOPMENT OF ANALYTICAL TECHNIQUES IN ANALYZING SYSTEMS OF MANAGING WATER QUALITY

The overall objective of water quality management is to regulate or control water resource uses so as to enhance or maximize man's satisfaction from this resource. This suggests that the management of water quality should center on the desires of water users. However, as increasing increments of improvement are desired, costs mount rapidly. Therefore, a framework within which "appropriate" quality levels and various alternative control methods can be considered becomes increasingly important. This chapter is devoted to developing such a framework in pursuing the five objectives of the study, which may be regarded as necessary subsets of the overall objective mentioned above. Application of the framework to a study area is presented in Chapter V.

No matter what form of control authority exists or is established, certain elements of the proposed framework are essential in seeking the study objectives. First, knowledge of water uses in the study area is needed, including both waste discharge and quality requirements by uses. Second, the physical system linking, i.e., hydrologic model, water uses must be specified, based on relationships obtained from the physical and biological sciences. This enables one to relate the source of constituents with the point of impact (use) via the transport mechanism. Third, a parametric linear programming constrained cost minimization model is developed, using various soil conserving practices as activities. The first three elements enable one to estimate the least-cost solution for achieving various specified levels of water quality at a particular point of use. A damage avoidance function was developed for municipal water use by comparing estimated treatment costs for various levels of intake water quality in Chapter VI. Combining the physical and economic systems enables one to suggest the "appropriate" level of water quality in a water use area. Finally, elements of the physical, economic, and institutional framework of a comprehensive water quality management system are posited. The research needs suggested by the study and a summary of the study are presented in Chapter VII.

Methodology for Developing Relevant Quality Constituents

Quality conflicts between uses of a particular water resource arise because the waste constituents of one use change the physical, chemical, and/or biological characteristics of that water which affects some subsequent use(s) of that water supply. This suggests that subsequent or potential water uses are the basis for a practical and effective quality management program. Therefore, the measurement of quality is in respect to some specified water use(s) and is dependent upon certain measurable constituents. These constituents may be physical, chemical, or biological parameters.

The specification of the constituents to be considered must be derived from a consideration of the uses within a water resource area. A matrix for specifying the constituents to be considered is shown in Table 2.

Table 2. Matrix of constituents by water uses

Constituents	Water uses Munici-pal	Food processing	Agriculture[a] Row	Rot.	Fish	Recreation
1. Waste						
Nitrates	x[b]		x			
Phosphorus	x		x			
Suspended solids	x		x			
etc.						
2. Requirements						
Nitrates	x				x	x
Phosphorus	x				x	x
Suspended solids	x				x	x
etc.						

[a] Row indicates continuous row crops and Rot. a rotation containing meadow.

[b] x would indicate the level of waste constitutes and required constituents by uses.

In particular, each water use has a number of related use conditions and effects. These related use conditions and effects on water quality can be identified and measured by the waste constituents of a particular use condition. By comparing the resultant water quality of a particular prior use with the desired constituents of a subsequent or potential use, the relevant constituents can be determined. Specifically, if the level of the constituent resulting from a particular use is higher than some desired level of a subsequent use, that constituent should be considered for it has the potential of affecting that use. To determine the effects of the use conditions on a subsequent use and thereby which uses are conflicting, the constituents must be applied to a physical resource, which is discussed in the following section.

Physical Linkage of Water Uses

The water use conflicts that result from conflicting constituent levels necessitatès a physical system linking the water uses. The physical linkage system of surface water pollution for the potential pollutants of sediment and phosphorus and the control methods is illustrated in Figure 2.

To make the model of the physical system manageable, several parts of the physical system are assumed to be constant. In the source section, rainfall, soil type, slope length, and slope gradient are assumed constant. While in the stream carriage system, the delivery ratio, stream flow, and the transport of sediment and phosphorus are assumed constant. In the use section, quality and quantity levels are specified for the uses considered. These fixed factors relate primarily to relationships taken from the physical sciences and those which require simplifying assumptions. This leaves only soil conservation practices and water supply treatment as variables in the physical system, the logic being that both soil conservation practices and water supply treatment are important water quality management techniques.

With the physical system presented in Figure 2 and the source and stream carriage factors assumed to be constant, one can predict the impact of alternative use conditions (land practices) on stream water

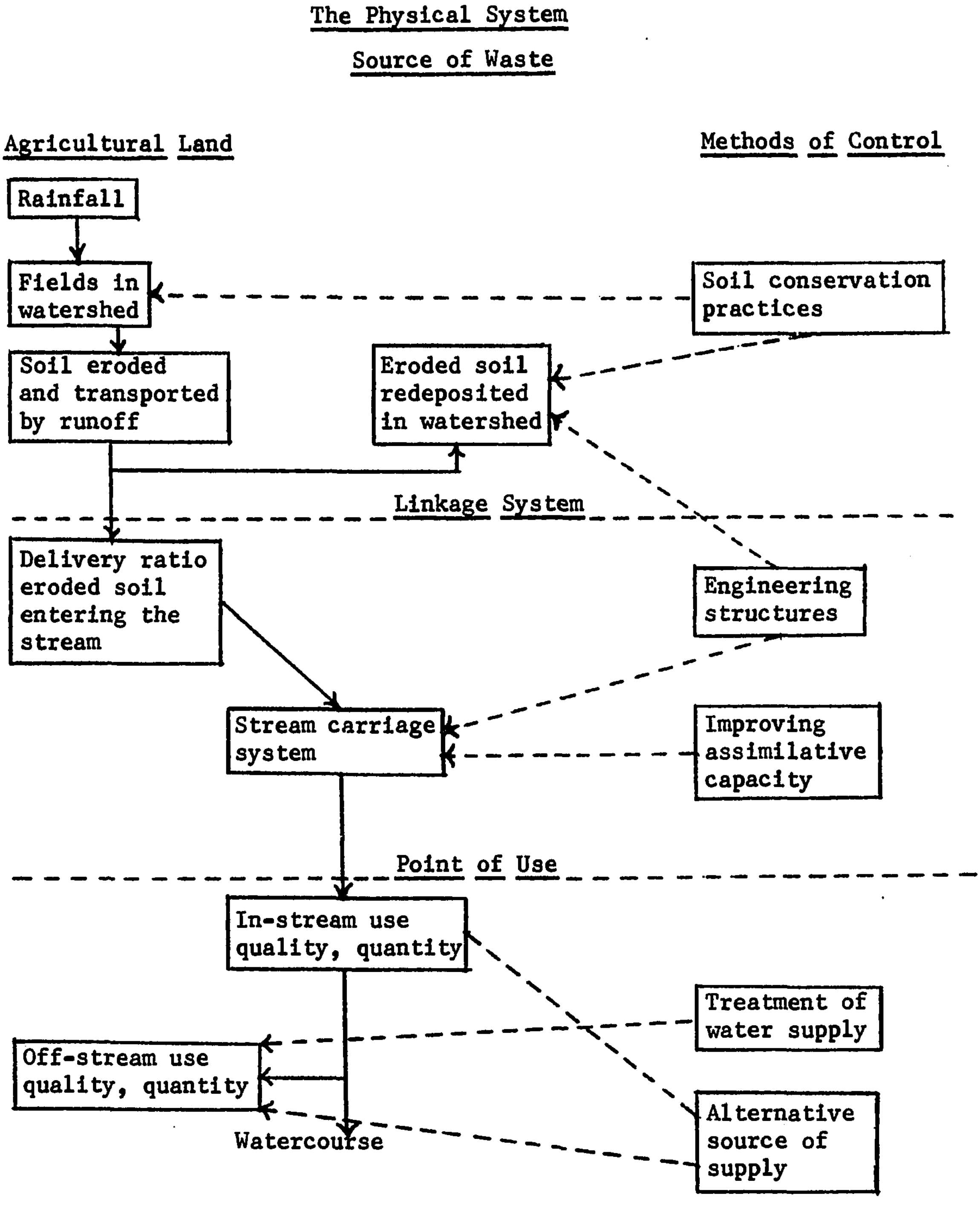

Figure 2. Diagramatic presentation of physical linkage system for sediment and phosphorus from agricultural lands

quality, i.e., sediment and phosphorus levels. A comparison of the predicted water quality under alternative use conditions and the specified quantity and quality of downstream uses will indicate when the uses will be conflicting. Assuming away the possibility of pristine quality, there is likely to be a divergence between stream quality and exogenously specified demand qualities. The physical system illustrated in Figure 2 provides use with the control methods for alleviating the divergence in quality. The methods of improving the quality of a water supply to that quality specified for a particular use can be accomplished through preventing the constituent from entering the water, in-stream practices, and/or treatment at the point of use. While the physical model provides information as to when conflicts will arise and the methods to control them, the questions of what level of quality and least-cost means of achieving that level remain. Since the physical analysis provides no criteria for choice, economic considerations must be brought into the analysis to answer the above questions. In the next section, the benefits and costs of alternative quality levels are discussed as a choice mechanism and to point up the information needed to aid in decision-making.

Benefits and Costs of Water Quality Levels

In moving from the physical to the economic framework, one of the essentials in formulating the economic analysis is the development of required empirical data. That is, the economist must be given the best information available relating physical, chemical, and biological conditions to the effects they have on water quality and thereby the uses of that water if they are to be incorporated into meaningful economic analysis. There are two fundamental premises basic to the development of the empirical data needed for economic analysis of water quality management. The first is that cost and technical coefficients can be developed for each of the alternative control measures. Moreover, these coefficients must differ because otherwise one control measure is the same as the other in terms of cost, and there would be no problem regarding which control method, but simply a question of what level of water quality. The latter question addresses itself to the second basic premise, which is that the benefits of water quality improvements to subsequent water uses can be estimated. These two premises suggest that an optimal water quality control program for a water use entity can be approached three ways:

1. Specify quality levels (standards) and determine the minimum total cost of abatement techniques which guarantee that the total amount of the constituents being considered will not exceed the specified upper limits.
2. Estimate the costs and benefits from incremental quality improvements and attempt to equate incremental benefits and costs of water quality control.
3. A combination of the two approaches.

It seems that while the benefit-cost approach is theoretically more desirable, the standards approach is more practical.[1] Since one of the objectives of this study is to develop a control program which will suggest the appropriate level of water quality and in view of the hard to measure benefits of quality improvement, a combination of the two approaches is used. A brief description of the methods for cost minimization and the benefits of quality control follows.

Constrained cost minimization

Referring to Figure 2, the alternative methods for controlling water quality are illustrated. The question of which control methods and at what level depends on (1) the level of water quality desired; (2) the unit cost coefficients of the alternative methods; and (3) the technical coefficients of the alternative methods, i.e., the unit effectiveness of each control method. If the cost and technical coefficients of the alternative methods can be developed, each of the techniques can be regarded as an activity and linear programming becomes the appropriate analytical tool to use. Since these coefficients can be developed and linear programming has been employed successfully in several other water quality management studies (85, 18, 81, 63, 88), linear programming appears to be the appropriate method to use in this study.

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[1] Kneese (57, especially Chapters 6 and 7) discussed the relative merits of these two approaches and the problems of measuring the benefits of quality improvement, i.e., the decreased damages to a subsequent use through the decreased discharges of a prior use.

In formulating the constrained cost minimization model, it is assumed soil and the accompanying phosphorus eroded from agricultural lands and transported to the stream via rainfall runoff is of prime concern in the river basin. The agricultural land in the basin is divided among six capability classes. For each class, it is assumed that certain soil conservation practices are possible, i.e., continuous row crops, particular rotation of row crops, grain and meadow, continuous row crops plus contour, etc. The combination of land classes and soil conservation practices and gully control structures provides the bundle of alternative water quality improvement techniques, which is represented by the vector, $x = (x_j)$, $j = 1,...,n$. The land runoff consists of m different types of constituents, of which only sediment and phosphorus are considered. The following data are then required:

a_{ij}, the amount of constituent m delivered to the stream from one acre of soil conservation practice x_j. The units of a_{ij} are in mg/l.

bm, the water quality level given in terms of the maximum concentration (mg/l) of the constituent(s) allowed in the stream. Other constraints are the amount of land in the various land classes, which are imposed in the b vector.[1]

c_j, the cost in dollars of one acre of a soil conservation practice x_j.

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[1] It should be mentioned that land constraints are presented as equalities since all land is subject to the erosion process regardless of the conservation practice.

The model then determines the set of variables x_j, which are interpreted as the level of the various soil conservation practices which minimizes the abatement costs. This model can be cast in the form

$$\text{Minimize } Z = c_1x_1 + c_2x_2 + \ldots\ldots + c_{11}x_{11} \qquad (1a)$$

$$\begin{aligned} \text{Subject to} \quad & a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \leq b_1 \\ & a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \leq b_2 \\ & \vdots \\ & a_{m1}x + a_{m2}x_2 + \ldots\ldots + a_{mn}x_n = b_m \\ & x_j \geqslant 0 \end{aligned} \qquad (1b)$$

When the linear programming problem formulated above is solved using any of the standard computer codes for this purpose, the minimum abatement cost $Z = Z^o$ and a treatment program $X_j = X_j^o$ for achieving this minimum cost is obtained. In addition, information which is useful in analyzing the water quality management system emerges. This information is referred to as "shadow prices" by economists, and "Lagrange Multipliers" by mathematicians. There is a multiplier associated with each constraint equation. The multipliers can be denoted by π_1, π_2, ..., π_m, respectively. By parametrically changing the constraints, the value Z of the minimum cost solution can be regarded as being a function of the right-hand side elements. Thus $\pi_m = \partial Z/\partial b_m$ represents the marginal increase in the minimum cost per unit decrease in the amount of constituent m allowable. Clearly $\pi_m \leq 0$ in that if more of a constituent is allowed less treatment would be required, decreasing the cost of the program. $\pi_m = 0$ means that for the optimal treatment program the amount of constituent m is strictly less than the allowable amount.

While the constrained cost minimization model provides the minimum total cost and the incremental cost of alternative quality levels, it begs the question of the "proper" level of stream quality.

To ascertain the "proper" quality level requires an investigation of the nature and costs of both the alternative activities open to A, the source, and their impact on the devices available to B, the user, to adjust to A's activities. This means that in addition to determining the minimum cost of achieving improved levels of water quality, the decreased treatment costs (benefits) to downstream uses must also be determined. This same idea is expressed by Kneese and Bower (57, p. 109) by what they call the "damage cost function," which is the functional relationship between the amount of a constituent withheld and damages avoided (benefits). If a damage avoidance function (benefits function) relating improved water quality levels to reduced damages to downstream uses could be developed, the "proper" level of water quality occurs where the incremental minimum cost equals the sum of the incremental damages avoided by downstream uses.

A study by Frankel (35) found that municipal water supply treatment benefits were low, therefore vast amounts of reuse are required to justify the additional abatement costs. Furthermore, Kneese and Bower (57, p. 125) report that industrial costs turn out to be surprisingly insensitive to intake water quality within comparatively wide ranges. This suggests that the decision of whether or not to maintain the higher levels of water quality will rest either on a large reuse of the water or almost entirely on aesthetic and recreational benefits. However, since there is no widely accepted method for estimating recreational benefits, a combination of the cost minimization and benefit-cost analysis is used to suggest the "proper" level of water quality in the basin.

In particular, since municipal use is the major use in the basin studied and information is available on water supply treatment costs and intake water quality, the decreased treatment cost associated with improved intake water quality will be used to estimate benefits. Thus, if municipal and recreational were the only uses, the total minimum abatement costs less the benefits to municipal uses indicates the minimum benefits to recreation for that quality level, i.e., the opportunities foregone by meeting that water quality requirement. While this still does not allow us to determine the optimal level of water quality, it provides more of the information needed for suggesting the "proper" level of water quality than the straight application of cost minimization does.

The development and application of the cost minimization model to a study entity and the results are presented in the next chapter.

CHAPTER V. DEVELOPMENT AND APPLICATION OF MODEL TO WATER QUALITY MANAGEMENT IN THE SYNTHESIZED NISHNABOTNA WATERSHED

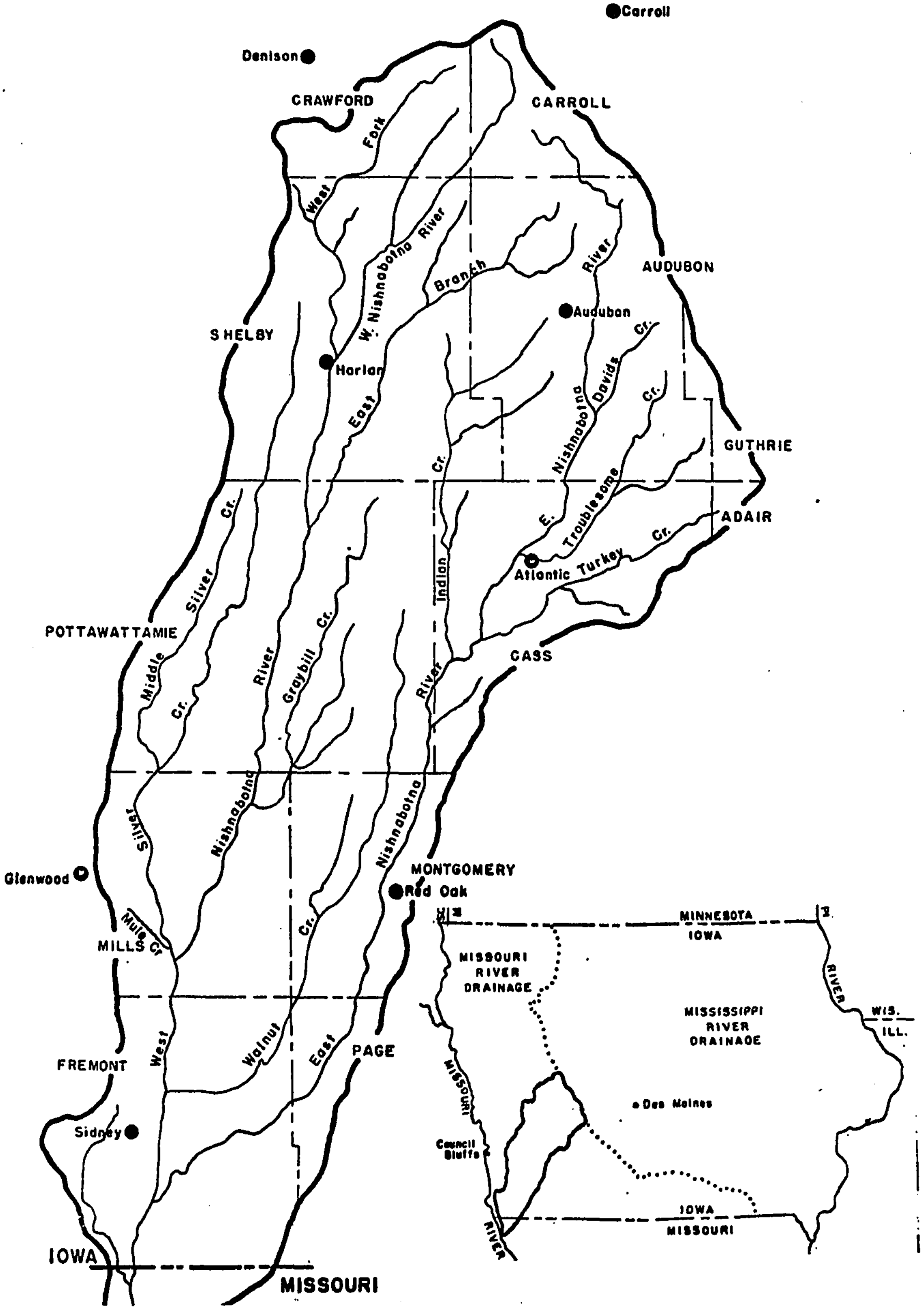
The Water Entity

The Nishnabotna River Basin (Figure 3) is the area to which the analytical framework presented in Chapter IV is applied. Located in Southwestern Iowa within the Missouri River Basin, the basin begins in the southern parts of Crawford and Carroll Counties and extends in a southwesterly direction through portions of 10 other Iowa counties and the extreme Northwest corner of Missouri (51, p. 3). The Nishnabotna River is the fifth largest river in Iowa (51, p. 3). Approximately 2,819 square miles (62, p. 3) or about 95 percent of the basin is located in Iowa. Only that portion of the basin lying within Iowa is considered in this study.

The principal resource of the basin is its soil, lying in the Marshall soils area of Southwestern Iowa. Marshall silt loam is the predominant soil type (51, p. 5). These soils developed under tall-grass prairies as the original vegetation and are highly productive and well adapted to a variety of crops (51, p. 5). Slopes in the Marshall silt loam areas range from gently to strongly sloping, with most slopes being between 2 and 11 percent (51, p. 5). While the topography assures adequate drainage, it is also conducive to high erosion.

Land use data for the study area were obtained from the 1967 Conservation Needs Inventory (50). The inventory process involved

Figure 3. The Nishnabotna River Basin


Carroll
Denison
CRAWFORD
CARROLL
West Fork
W. Nishnabotna River
Branch
River
AUDUBON
Audubon
SHELBY
Harlan
East
Davids Cr.
Nishnabotna
Cr.
GUTHRIE
Cr.
E. Troublesome Cr.
ADAIR
Silver Cr.
Indian
Atlantic
Turkey Cr.
POTTAWATTAMIE
Middle Silver Cr.
River
Graybill Cr.
River
CASS
Nishnabotna
Nishnabotna
Silver
Glenwood
MONTGOMERY
Red Oak
Mule Cr.
MILLS
Cr.
FREMONT
West
Walnut
East
PAGE
Sidney
IOWA
MISSOURI
MINNESOTA
IOWA
MISSOURI RIVER DRAINAGE
MISSISSIPPI RIVER DRAINAGE
RIVER
WIS.
ILL.
MISSOURI
Des Moines
Council Bluffs
IOWA
MISSOURI
RIVER

randomized sets of samples in each county representing approximately 2 percent of the county area (50, p. 224). The standard sample unit size was 160 acres. For each sample area, the acreages of land uses by land capability classes were determined and the data extended giving total acreages by county. To obtain the same information for the Nishnabotna River Basin, the percent of the county in the Nishnabotna River Basin was determined for each of the 12 counties.[1] By taking these percents times the county acreages and summing them, an estimate of the acreages of land uses by land capability classes was obtained for the basin. A summary of the land uses by land capability classes for the Nishnabotna River Basin is shown in Table 3.[2]

Table 3 shows that nearly 1.73 million acres are included in the inventory. The total basin area is 2,819 square miles or approximately 1.80 million acres, indicating that over 96 percent of the basin area is included in the inventory.

Of the land uses presented in Table 3, only crop and pasture land are included in the study because the focal point of the study is controlling pollutants from agricultural land. Calculated from Table 3, the total acreages of "row crops," "close grown crops," and "hay and pasture land" are about 1.60 million acres or just under 89 percent of

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[1] The drainage area of the Nishnabotna River for each of the 12 counties was obtained from Larimer (62).

[2] It should be noted that the inventory does not include federal land, urban land, and small streams and ponds.

Table 3. Land use by capability classes for the Nishnabotna River Basin[a]

Capability class and subclass	Slope gradient[b] %	Row crops	Close grown crops	Hay and pasture land[c]	Forest land	Other land	Total
		acres					
I	1-1.9	93,847	5,669	26,633	8,507	4,337	138,993
II	2.0-4.9	317,662	35,763	200,315	6,696	17,428	577,864
E		175,532	24,660	97,386	3,944	12,927	314,449
III	5.0-13.9	351,307	55,737	293,996	17,427	19,351	737,818
E		322,911	53,521	279,593	15,951	18,154	690,130
IV	14.0-19.9	53,374	14,248	80,141	4,899	2,628	155,290
E		51,848	14,121	78,982	4,683	2,628	152,262
V	-	2,869	-	7,011	2,468	227	12,575[d]
VI	20.0-29.9	10,102	2,768	36,208	17,328	899	67,305
E		9,223	2,768	35,793	17,328	772	65,884
VII	20.0+	1,407	840	13,281	16,728	6,517	38,773
E		1,298	840	13,211	16,512	6,411	38,272
Class totals		830,568	115,025	657,585	74,053	51,387	1,728,618
Subclass E totals		560,812	95,910	504,965	58,418	40,892	1,260,997

[a] Land use by capability classes for Nishnabotna basin was calculated from (62, 50).

[b] Slope gradient taken from (85, Table 1, p. 57).

[c] This includes conservation use presented in (50).

[d] Excluded from the study.

the basin and more than 92 percent of the lands included in the inventory. Summing these same land use categories for subclass E (erosive soils) indicates more than 72 percent of the agricultural lands fall into this subclass. Since agriculture is the major land use in the basin and the majority of the land is highly erosive, the Nishnabotna River Basin provides an excellent study area for analyzing agricultural practices and surface water quality.

Estimating Soil and Phosphorus Losses

Where agricultural lands are a major sediment source, the universal soil-loss equation provides a procedure for computing expected average annual soil loss from alternative land practices on a particular land area. Use of the universal soil-loss equation and some of its limitations are presented in Wischmeier and Smith (128, pp. 38-48) and were discussed in the physical section of Chapter III. Because of the limitations of applying the soil-loss equation to a large geographic area and the assumptions required, the physical system developed and the results obtained are not directly applicable to the Nishnabotna Basin. However, the purpose of the study is to develop a framework for water quality management and not precise estimates of erosion. Basic to the approach is determining the physical effectiveness of alternative management techniques. Since the universal soil-loss equation enables us to compare the effectiveness of alternative conservation practices, its use in developing the physical entity with certain data taken from the basin seems to be justified.

The universal soil-loss equation is (128, p. 3):

$$A = RKLSCP \tag{2}$$

where A is the computed soil loss in tons per acre per year

R the rainfall factor,

K the soil-erodibility factor,

L the slope-length factor,

S the slope-gradient factor,

C the cropping-management factor, and

P the erosion-control practice factor.

The equation indicates that the rate of soil erosion in any area is influenced by rainstorm characteristics, land slope, crop cover, management and soil properties. Since rainstorm characteristics, land slope, cover, and management may influence soil erosion more than the properties of soil, the soil-erodibility factor, K, must be evaluated independently of the other factors. To evaluate the K-factor, the soils were kept in a cultivated continuous fallow condition. When an area is under continuous fallow, RKLS will give us the average annual soil loss. This would represent maximum erosion, which could be reduced through crop rotations, tillage systems and/or erosion control practices. The quantitative values of each of the factors in the equation are discussed next.

The R-factor is a measure of the erosive force of a normal year's rainfall. A value of 168 is used for the R-factor in this study. This value is interpolated for the basin midpoint from the iso-erodent map in Wischmeier and Smith (128, pp. 6-7).

As mentioned previously, Marshall silt loam is assumed to be the only soil type in the basin. Reading from Table 1 in Wischmeier and Smith (128, p. 5), the soil-erodibility factor, K, for Marshall silt loam is 0.33.

Soil erosion by rainfall is very much affected by both slope length and gradient. It is convenient to express the two as a single topographic factor, LS. LS values can be computed by solving the following equation:

$$LS = f^{\frac{1}{2}}(0.0076 + 0.0053s + 0.00076s^2) \qquad (3)$$

where f is the slope length in feet and s is the gradient in percent. For the s values, the midpoint of the slope gradient ranges of the various capability classes were used, except for class VII where 30 percent was used. Values of 300 feet for capability classes I and II and 600 feet for capability classes III, IV, VI, and VII were the f-values used. These values were obtained from Seay's study (85, p. 59). When terraces occurred on capability classes II, III, and IV, the s and f values used were 4, 10, 18 and 188, 138, 118, respectively. The source of these values was a technical guide for conservation practices (94). The computed LS values for the various capability classes are summarized in Table 4.

Crop management factors, C, for two crop rotations and two tillage systems are developed in Tables 22-25 in Appendix A. These values and P, the conservation control practices, factor values are discussed later with the development of the activities.

Table 4. LS values by capability class for specified slope lengths and slope gradients

Capability class	Slope gradient %	Slope length (ft)				
		118[a]	138[a]	188[a]	300	600
I	1				.2366	
II	3.5				.6142	
	4.0[a]			.5616		
III	9.5					3.0996
	10[a]		1.6047			
IV	17					7.7732
	18[a]	3.7937				
VI	25					15.0668
VII	30					20.8354

[a] These are the s and f values for terraces; source: (94).

Once values for the factors in the soil-loss equation are obtained, it can be used to predict and compare soil losses under alternative conservation techniques. Since phosphorus has been designated as the nutrient most likely to be limiting in our natural waters,[1] a technique for estimating phosphorus losses under alternative conservation practices appears to be of major importance. In developing an equation to estimate phosphorus losses, three important facts about phosphorus were given prime considerations.[2] The three facts considered were:

(1) there is a positive relationship between erosion and phosphorus losses,

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[1] See Chapter II, p. 22.

[2] The three important facts were presented in Chapter III, pp. 41-42.

(2) phosphorus is relatively immobile in soil, so phosphorus losses from agricultural lands occur primarily from phosphorus absorbed on eroded soil,

(3) erosion is selective in its removal of phosphorus.

It appears that, with the immobility of phosphorus in soil and the selectivity of the erosion process, phosphorus losses could be estimated by adding the phosphorus content in the topsoil and a selectivity factor on to the soil-loss equation. Thus, the equation developed to predict phosphorus losses is

$$Np = ASpE \tag{4}$$

where Np is the lbs. of phosphorus loss per acre per year,

A, tons of soil lost per acre per year,

Sp, lbs. of phosphorus per ton of topsoil,

E, enrichment ratio for phosphorus, i.e., the increased concentration of phosphorus in eroded soil relative to the original topsoil.

The only new factors in the equation are Sp and E. A value for Sp can be calculated from the lbs. of phosphorus per acre, in the top 6 or 7 inches of soil, divided by the tons of soil per acre. In the study area, the lbs. of phosphorus per acre and the tons of soil per acre were estimated to be 1200 lbs. and 1,000 tons, respectively.[1] Dividing, one obtains an Sp-factor of 1.2 lbs. of phosphorus per ton of soil.

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[1] Values were obtained from a personal conversation with Dr. Thomas E. Fenton, Agronomy Department, Iowa State University, June 18, 1971.

However, this is not the final estimate of the phosphorus lost because of the selectivity of the erosion process. Simply stated, this means that the phosphorus content of eroded soil is higher than in the original topsoil. The extent of this increase has been called the "enrichment ratio" and has been reported at from 2 to 3.5 for phosphorus.[1] To obtain a quantitative value for the E-factor, the equation developed by Massey et al. (66, p. 354) is used. Their enrichment equation for phosphorus is:

$$Yp = .319 + .250X + .098Z \qquad (5)$$

where Yp is the log enrichment ratio for phosphorus,

X, -log tons of solids per acre-inch of runoff,

Z, -log tons of solids lost per acre.

Using this equation, values for the E-factor were obtained for the various conservation practices.[2] These enrichment ratio values and the final estimated lbs. of phosphorus lost per ton of topsoil are developed in Table 28, Appendix A.[3]

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[1] See Chapter III, p. 42.

[2] It should be noted that the equation developed by Massey and Jackson was for soil loss samples with average soil losses ranging from about 0.4 to 1.5 tons per acre. Therefore, the applicability of the equation to some of the higher soil loss rates in the study area has not been tested. But remember, the objective of the study is not a precise estimate of phosphorus losses but an approach to water quality management. Moreover, the soil loss from most of the activities that appear in the program solutions are not that much greater than those used by Massey and Jackson, ranging from 0.51 to 11.55 tons per acre.

[3] Since the various combinations of crop rotations, tillage systems and land treatment practices are presented in Table 18 for the first time, an explanation of the abbreviations seems appropriate. "Conv.till."= conventional tillage. "Min.till."= minimum tillage. "R_1"=Corn-corn-soybean rotation. "R_2"=corn-soybean-corn-oats-meadow-meadow rotation. "Perm.past."=permanent pasture.

Using the phosphorus-loss equation developed, the estimated phosphorus losses for "Conv. till. - R_1" and "Conv. till. + contour- R_2", on capability class two land, are 5.34 and 3.25 lbs/acre/yr, respectively. These losses are comparable with phosphorus losses reported in (115, p. 8; 123, p. 383; 7, p. 523) for corn under similar land practices and soil losses. The next section deals with the development of programming activities, in which the sediment and phosphorus-loss equations are applied.

Developing Programming Activities

Earlier reference was made to the need of some simplifying assumptions. In view of the less than perfect knowledge concerning soil erosion and phosphorus losses and their transport, certain assumptions are needed to relate these to land practices and hydrologic data. The innumerable combinations of land use, topography, and hydrologic data make further simplifications necessary to deem the physical system tractable.

Land characteristics

In applying the soil-loss equation to a large tract of land, certain assumptions regarding soil type and topography are needed. One assumption, which was stated before, is that Marshall silt loam is the only soil type in the basin. Another assumption, because of aggregative nature of land use data by capability classes, was that a single slope gradient and slope length could be used for land in a particular capability class. Barring a complete survey of land in the basin, no means for a more precise breakdown of topography for the land area could be developed.

Cropping systems

To limit the number of activities in the program, only three land uses are allowed. Specifically, the land uses allowed in the basis are a corn-corn-soybean rotation, a corn-soybean-corn-oats-meadow-meadow rotation, or permanent pasture. Looking again at Table 3, the class totals for "row crops," "close grown crops," and "hay and pasture land" suggest the sod-based rotation mentioned above. However, continuous row crops constitute the major land use in the basin, so both rotations are used in this study. In addition, permanent pasture is allowed as an alternative; indeed, it is forced into capability classes VI and VII based upon the recommendation of soil scientists that the steeper sloped classes are not suited for row crops (50, p. 226). It is also assumed that all the agricultural land in the basis is in one of these three uses, i.e., no fallow land is allowed. Furthermore, since the Conservation Needs Inventory specifies how the land is used rather than how it could be used, the three use categories in Table 3 are combined into one value for each capability class.

Farming units

Knowledge of the size of farm production units is required in developing the cost coefficients for the activities of the program. In this study, the 450 acre units hypothesized by Seay (85, p. 62) are used. By using the same size production unit, the results will be more readily comparable.

Stream sediment and phosphorus

With the concentration of sediment and phosphorus in the stream being of prime concern, knowledge of the amount entering the stream and stream flow is necessary. To determine that part of total eroded soil and phosphorus delivered to the stream, the delivery-ratio of .25 calculated by Seay (85, p. 75) is used. In addition, delivery-ratios of .20 and .30 are also used to analyze the sensitivity of the results to the delivery-ratio. For streamflow, the long term average annual streamflow and sediment concentration were used because the soil-loss equation gives long term (25 years or longer) average annual soil losses. Furthermore, it is assumed that erosion occurs only from cropland and that upon entering the stream the eroded sediment and phosphorus are carried in suspension by the stream. It is realized that rainfall patterns, erosion, streamflow, and resulting sediment and phosphorus loads are extremely complex and variable phenomena. But the basic data and knowledge needed to relate these phenomena are not available. Thus, these rather gross simplifications were needed in developing the empirical data for the programming activities. Again the reader should be reminded that the main objective of the study is a basic framework for water quality management rather than numerical results. In this respect, the simplifying assumptions are not so disturbing.

With these assumptions, the basin is reduced to an area of rolling cropland, comprised of 450-acre production units. The concentration of sediment and phosphorus in the stream varies with the cropping systems and conservation practices used on the cropland. It is the combination of cropping systems and conservation practices that make up the activities of the linear program. Specifically, the activities developed involve combinations of cropping systems, tillage systems, and land treatment practices. In addition, permanent pasture and gully control structure activities are developed. A summary of the activities allowed by capability class is presented in Table 5.

For each activity developed, a corresponding physical coefficient specifying the per unit contribution of each activity and their unit cost must be calculated. Derivation of these coefficients are described in the following sections.

Crop and tillage systems

In combination with the two crop rotations presented earlier, two tillage systems are considered. The most common is "conventional tillage," which is the long practiced plow-disk-plant-cultivate sequence. The other system is called "minimum tillage" and is a no-plow system. It consists of leaving crop residue on the surface and ridge planting of row crops. For each of the alternative cropping-tillage systems, crop-management values (C-factors) are derived in Tables 22-25 in Appendix A. Knowing the C-factor values, the estimation of soil and phosphorus losses are derived by the direct application of the soil and phosphorus-

Table 5. Programming activities allowed by capability class

Programming activities	Capability classes I	II	III	IV	VI	VII
Conventional tillage:						
R_1[a]	X[c]	X	X	X		
R_2[b]	X	X	X	X		
R_1 + contouring	X	X				
R_2 + contouring	X	X				
R_1 + terraces		X	X	X		
R_2 + terraces		X	X	X		
Minimum tillage:						
R_1[a]	X	X	X	X		
R_2[b]	X	X	X	X		
R_1 + contouring	X	X				
R_2 + contouring	X	X				
R_1 + terraces		X	X	X		
R_2 + terraces		X	X	X		
Gully control structures		X	X	X	X	X
Permanent pasture	X	X	X	X	X	X

[a] R_1 designates the corn-corn-soybeans rotation.

[b] R_2 designates the corn-soybeans-corn-oats-meadow-meadow rotation.

[c] X indicates those activities allowed in the various capability classes.

loss equations. The computed soil and phosphorus losses for each combination for the capability classes where row crops are allowed are found in Tables 26-28 in Appendix A.[1]

Land treatment practices

Two land treatment practices are considered in the study, namely contouring and terracing. The erosion control practice factor (P-factor) is unity in the prediction equations for the various crop-tillage systems. After obtaining the appropriate P-factor for contouring and terraces (128, Table 6, p. 36; 85, Table 13, p. 128), applying these values to the soil-loss equation will give estimates of erosion for each of the alternative cropping-tillage-land treatment systems. Furthermore, applying the predicted soil losses to the phosphorus prediction equation provides estimated phosphorus losses for these same systems. Derivation of the predicted soil and phosphorus losses for each capability class, where the cropping-tillage-land treatment systems are allowed,[2] are presented in Tables 28-31 in Appendix A.

Permanent pasture

Obtaining the C-factor for permanent pasture from Wischmeier and Smith (128, Table 2, lines 120-122, p. 14), soil-loss estimates are

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[1] These values assume that cultivation consists of up and down the slopes without regard to contour. Contouring and terraces are regarded as land treatment practices and are discussed next.

[2] It should be noted that contouring is not allowed in capability classes III and IV because of the limiting slope lengths for effective contouring (128, Table 7, p. 37).

obtained by simply plugging these values into the soil-loss equation. Again, phosphorus losses are obtained by applying the above soil losses to the phosphorus prediction equation. The computed phosphorus and soil loss values for all six capability classes are given in Tables 28 and 32, respectively.

Having developed the physical coefficients, the next step is the derivation of cost coefficients for each activity. The starting point was determining the fixed and variable production costs of conventional and minimum tillage under both rotations. To derive these costs, a set of machinery must be specified. In specifying the machinery set the timeliness of planting and harvesting are deemed the principal variables. More specifically, the farm operator in southern Iowa knows his corn yields begin to decrease if the corn is not planted by about May 12 or harvested by about October 28 (53, Table 1.28, p. 35). To develop a set of machinery for a 450-acre unit to allow the various operations to be completed before the "critical date," information on the average number of days available for field work per week (53, Table 1.25, p. 31) and the field time requirements (hr/ac) of various sized machines (126, pp. 136-138) is needed. By specifying a starting date for planting and harvesting, combined with the above information, it was possible to specify such a machinery set. The machinery sets, the time requirements for the four alternative crop-tillage systems on class I and II lands, and the associated fixed and variable costs are derived in Tables 37-47 of Appendix B.

Viewing the labor and field time requirements for conventional tillage and minimum tillage in Tables 38, 39, and 41, one observes that the latter requires less time and is therefore less expensive. This is logical in that minimum tillage involves fewer operations. Similarly, time requirements for field operations have been found to vary when farming on flat land, on the contour, and on parallel terraces (53, p. 40). Furthermore, James (53, p. 40) indicates that parallel terraces can be farmed about as efficiently as flat land. Therefore, it is assumed that the time requirements and variable costs are the same for parallel terraces as for flat land. However, one would expect field operations on upland, i.e. capability classes III and IV, and on the contour to require more time and thereby be more expense than the same operations on flat land. The 1.32 factor used by Seay (85, p. 68) is used to adjust the upland and contour operating times and variable costs. This factor is based on a study by Smith (87), that indicates a 32 percent increase in farming time for operations performed on non-parallel terraces compared to the same operations on parallel terraces. Since flat land and parallel terrace operations are assumed to have the same time requirements, by applying this factor to upland and contour operations, it is implicitly assumed that they have the same increased time requirements as non-parallel terraces. With this adjustment, production costs for the four cropping-tillage systems as performed on flat lands, uplands, contour, and parallel terraces can be determined. Computations of these costs are shown in Tables 48 and 49 in Appendix B.

As noted in Tables 48 and 49, production costs developed therein do not include fertilizer, seed, chemical, and storage costs. These costs are developed in Tables 50 and 51 of Appendix B. While the seed, chemical, and storage costs are straightforward, an explanation of how fertilizer rates were determined in deriving the associated fertilizer costs seems appropriate. Nutrient needs are determined in a four-step procedure:

(1) A soil sample representative of a given area,

(2) Soil test procedures to measure nutrient availability,

(3) Interpretation of test results,

(4) Fertilizer recommendation based on the management situation (118, p. 1).

The test results of nutrient availability for samples of Marshall soil were obtained from Voss (119, Table 8A, p. 40). In addition, the subsoil phosphorus and potassium levels were taken from Voss (117, p. 14). Knowing the nutrient levels of Marshall soils and the two cropping systems, recommended nutrient rates for each crop based on management are made from Voss (116, 118). Having the recommended rates for each crop, the average fertilizer level and associated cost can be calculated for each crop rotation. These values are derived in Table 50, as stated earlier. Thus, the total production costs can be obtained by summing the appropriate values in Tables 48, 49, and 51.

The renovation and maintenance cost for pasture is calculated in a similar manner. Derivation of these data are presented in Table 52 of Appendix B.

The production costs have now been specified for each of the alternative cropping-tillage systems, plus combinations with land control practices, and for permanent pasture. However, these costs are but the beginning of a number of calculations needed to obtain the opportunity cost of each activity. The opportunity cost is the cost of not using that activity yielding the highest net return in a capability class, which is the cost used in the program. Thus, the derivation of opportunity costs requires the calculation of net returns for each activity. The additional calculations needed for this are the gross revenues for the two crop rotations and permanent pasture by capability class, plus a charge to land and the costs of constructing and maintaining parallel terraces. These revenues and costs are derived in Tables 53 and 54 of Appendix B.

A summary of production costs, gross revenues, land charges, terrace costs, and the associated net returns and opportunity costs for each activity by capability class are shown in Table 6.

Gully control

The final activity developed for the cost minimization program is the gully control structures. The gully activity differs from the other activities in that its physical coefficient represents the amount of sediment or phosphorus withheld from the stream rather than the amount deposited as was true of the other activities. Furthermore, there is no opportunity cost involved in gully structures. This means that the

Table 6. Opportunity cost of alternative crop, tillage and land practice systems

Capability class	Management system	Gross revenue[a] ($/ac)	Production costs		Land charge[a] ($/ac)	Terrace cost[d] ($/ac)	Net return ($/ac)	Opportunity cost ($/ac)
			Machine, and labor[b] ($/ac)	seed, chemical and fertilizer[c] ($/ac)				
I	Conv. till.-R_1	114.24	30.74	19.70	36.30	-	27.50	6.38
	Conv. till.-R_2	90.21	28.50	13.37	36.30	-	12.04	21.84
	Conv. till.+contour-R_1	114.24	34.49	19.70	36.30	-	23.75	10.13
	Conv. till.+contour-R_2	90.21	32.39	13.37	36.30	-	8.15	25.73
	Min. till.-R_1	114.24	24.36	19.70	36.30	-	33.88	-
	Min. till.-R_2	90.21	24.35	15.58	36.30	-	13.98	19.90
	Min. till.+contour-R_1	114.24	26.87	19.70	36.30	-	31.37	2.51
	Min. till.+contour-R_2	90.21	27.50	15.58	36.30	-	10.83	23.05
	Perm. past.	57.40	-	18.67[e]	36.30	-	2.43	31.45
II	Conv. till-R_1	109.74	30.74	19.70	33.48	-	25.82	6.38
	Conv. till.-R_2	87.08	28.50	13.37	33.48	-	11.73	20.47
	Conv. till.+contour-R_1	109.74	34.49	19.70	33.48	-	22.07	10.13
	Conv. till.+contour-R_2	87.08	32.39	13.37	33.48	-	7.84	24.36

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[a] Taken from Table 53.

[b] Taken from Table 48 and Table 49.

[c] Taken from Table 51.

[d] Taken from Table 54.

[e] Taken from Table 52.

Table 6. (Continued)

			Production costs					
Capability class	Management system	Gross revenue[a] ($/ac)	Machine, seed, and labor[b] ($/ac)	chemical and fertilizer[c] ($/ac)	Land charge[a] ($/ac)	Terrace cost[d] ($/ac)	Net return ($/ac)	Opportunity cost ($/ac)
II	Min. till.-R_1	109.74	24.36	19.70	33.48	-	32.20	-
	Min. till.-R_2	87.08	32.39	13.37	33.48	-	7.84	24.36
	Min. till.+contour-R_1	109.74	26.87	19.70	33.48	-	29.69	2.51
	Min. till.+contour-R_2	87.08	27.50	15.58	33.48	-	10.52	21.68
	Conv. till.+terrace-R_1	109.74	30.74	19.70	33.48	7.40	18.42	13.78
	Conv. till.+terrace-R_2	87.08	28.50	13.37	33.48	6.80	4.93	27.27
	Min. till.+terrace-R_1	109.74	24.36	19.70	33.48	7.67	24.53	7.67
	Min. till.+terrace-R_2	87.08	24.35	15.58	33.48	6.92	6.75	25.45
	Perm. past.	56.00	-	18.67[e]	33.48	-	3.85	28.35
III	Conv. till.-R_1	96.38	34.49	19.70	24.80	-	17.39	7.62
	Conv. till.-R_2	76.38	32.39	13.37	24.80	-	5.82	19.19
	Min. till.-R_1	96.38	26.87	19.70	24.80	-	25.01	-
	Min. till.-R_2	76.38	27.50	15.58	24.80	-	8.50	16.51
	Conv. till.+terrace-R_1	96.38	30.74	19.70	24.80	12.11	5.28	19.73
	Conv. till.+terrace-R_2	76.38	24.36	19.70	24.80	13.11	14.41	10.60
	Min. till.+terrace-R_1	96.38	24.36	19.70	24.80	13.11	14.41	10.60
	Min. till.+terrace-R_2	76.38						
	Perm. past.	49.00	-	18.67[e]	24.80	-	5.53	19.48
IV	Conv. till.-R_1	72.35	34.49	19.70	18.15	-	0.01	7.62
	Conv. till.-R_2	57.14	32.39	13.37	18.15	-	-6.77	14.40
	Min. till.-R_1	72.35	26.87	19.70	18.15	-	7.63	-
	Min. till.-R_2	57.14	27.50	15.58	18.15	-	-4.09	11.72
	Conv. till.+terrace-R_1	72.35	30.74	19.70	18.15	12.04	-8.28	15.91
	Conv. till.+terrace-R_2	57.14	28.50	13.37	18.15	10.44	-13.32	20.95
	Min. till.+terrace-R_1	72.35	24.36	19.70	18.15	13.85	-3.71	11.34
	Min. till.+terrace-R_2	57.14	24.35	15.58	18.15	11.31	-12.25	19.88
	Perm. past.	39.00	-	18.67[e]	18.15	-	2.18	5.45
VI	Perm. past.	30.00	-	18.67[e]	10.09	-	1.24	-
VII	Perm. past.	27.00	-	18.67[e]	6.05	-	2.28	-
	Gully							1171.21[f]

[f] Taken from Table 55.

construction cost of gully structures can be used directly as the cost coefficient in the objective function.

Development of the physical retention coefficients (sediment and phosphorus) for gully control structures are shown in Table 33 of Appendix A. The cost coefficient for gully structures is taken from Seay (85, Table 24, p. 155). In addition, a limit on the number of gully structures permitted in the basin is calculated in Table 33 of Appendix A. The limiting number of structures allowed in capability classes II, III, IV, VI, and VII is computed by dividing the acres of erosive soils (subclass E) in each class by the average number of acres per gully structure. The program then permits gully control structures to be built in each capability class up to the limit based on the amount of subclass E land.

Sediment and phosphorus concentrations

All of the physical coefficients (sediment and phosphorus losses) calculated so far for the various activities are in terms of units per acre, except for the gully coefficients. Since the focus of the study is a stream quality, these coefficients need to be expressed as a concentration, i.e., weight of sediment or phosphorus per weight of a given volume of water. Thus, in calculating the concentration of a constituent, the weight of a specified volume of water must be determined, e.g., tons/ac.-ft.=1358.4156.[1] Since the concentration of a constituent in

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[1] This computation is based on the fact that a cu. ft. of water at 60°F weighs 62.37 lbs.

water is generally expressed in parts per million (ppm),[1] a general formula for expressing concentration in ppm is as follows:

$$\text{Concentration (ppm)} = \frac{Q_c}{1358.4186\ (Q_w)} \times 1{,}000{,}000$$

where

Q_c = quantity of constituent in tons

Q_w = quantity of water in ac.-ft.

By dividing 1,000,000 by 1358.4186, the equation is reduced to:

$$\text{Concentration (ppm)} \quad = \frac{Q_c}{Q_w} \times 736.1501\ .$$

Furthermore, since only long term average annual flow is used, taking the average yearly runoff of 796,125 ac.-ft. from Table 34 of Appendix A, the equation can be reduced to:

$$\text{Concentration (ppm)} = .9247 \times 10^{-3} \times Q_c\ .$$[2]

Therefore, one ton ($Q_c = 1$) of eroded soil or phosphorus entering the stream adds $.9247 \times 10^{-3}$ ppm to the stream load. A summary of the stream sediment coefficients for each activity by capability class is shown in Table 7.

While total phosphorus losses are computed in a manner analogous to sediment losses, there is one major difference, that difference being that only that portion of total phosphorus in solution, i.e., available phosphorus is of concern as far as quality management.[3] To determine

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[1] PPM is equivalent to milligram per liter (mg/l) for all practical purposes.

[2] Since phosphorus is expressed in pounds, this equation can be converted by dividing by 2000, i.e., $.9247 \times 10^{-3}/2000 \times Q_c$.

[3] See Chapter II, p. 16 and Chapter III, p. 37 .

Table 7. Estimated soil losses under alternative crop, tillage and land practice systems

Capability class	Management system	Erosion[c]	Sediment delivery ratios[a]			Concentration delivery ratios[b]			Add-on for gullying[d]	Sediment contribution /acre deliv. ratios		
			.20	.25	.30	.20	.25	.30		.20	.25	.30
			tons/acre			10-3 mg/l						
I	Conv.till.-R_1	5.41	1.082	1.352	1.623	1.001	1.251	1.501	0.215	1.216	1.466	1.716
	Conv.till.-R_2	2.13	0.426	0.532	0.639	0.394	0.492	0.591	0.085	0.479	0.577	0.676
	Conv.till.+contour-R_1	3.25	0.650	0.812	0.975	0.601	0.751	0.902	0.129	0.730	0.880	1.031
	Conv.till.+contour-R_2	1.28	0.256	0.320	0.384	0.237	0.296	0.355	0.051	0.288	0.347	0.406
	Min.till.-R_1	2.51	0.502	0.627	0.753	0.464	0.580	0.696	0.100	0.564	0.680	0.796
	Min.till.-R_2	1.08	0.216	0.270	0.324	0.200	0.250	0.300	0.043	0.243	0.293	0.343
	Min.till.+contour-R_1	1.51	0.302	0.377	0.453	0.279	0.349	0.419	0.060	0.339	0.409	0.479
	Min.till.+contour-R_2	0.65	0.130	0.162	0.195	0.120	0.150	0.180	0.026	0.146	0.176	0.206
	Perm.past.	0.05	0.010	0.012	0.015	0.009	0.012	0.014	-	0.009	0.012	0.014
II	Conv.till.-R_1	14.05	2.810	3.512	4.215	2.598	3.248	3.898	0.560	3.258	3.808	4.458
	Conv.till.-R_2	5.53	1.106	1.382	1.659	1.023	1.278	1.534	0.220	1.243	1.498	1.754
	Conv.till.+contour-R_1	7.02	1.404	1.755	2.106	1.298	1.623	10.947	0.280	10.578	1.903	2.227
	Conv.till.+contour-R_2	2.76	0.552	0.690	0.828	0.510	0.638	0.766	0.110	0.620	0.748	0.876
	Min.till.-R_1	6.51	1.302	1.627	1.953	1.204	1.505	1.806	0.259	1.463	1.764	2.065
	Min.till.-R_2	2.79	0.558	0.697	0.837	0.516	0.645	0.774	0.111	0.627	0.756	0.885
	Min.till.+contour-R_1	3.26	0.652	0.815	0.978	0.603	0.754	0.904	0.130	0.733	0.884	1.034
	Min.till.+contour-R_2	1.40	0.280	0.350	0.420	0.259	0.324	0.388	0.056	0.315	0.380	0.444
	Conv.till.+terrace-R_1	0.39	0.078	0.097	0.117	0.072	0.090	0.108	-	0.072	0.090	0.108
	Conv.till.+terrace-R_2	0.15	0.030	0.037	0.045	0.028	0.035	0.042	-	0.028	0.035	0.042
	Min.till.+terrace-R_1	0.18	0.036	0.045	0.054	0.033	0.042	0.050	-	0.033	0.042	0.050
	Min.till.+terrace-R_2	0.08	0.016	0.020	0.024	0.015	0.018	0.022	-	0.015	0.018	0.022
	Perm.past.	0.14	0.028	0.035	0.042	0.026	0.032	0.039	-	0.026	0.032	0.039

[a] Calculated by taking the delivery ratio times erosion.

[b] Calculated from the relationship: $.9247 \times 10^{-3}$ (tons/acre of sediment delivered).

[c] Taken from Tables 26-32.

[d] Assuming that Conv.till.-R_1 represents the average soil loss from gullying, the gully add-on coefficients are calculated from the following relationship:

$$\frac{\text{Tons/acre of class and system considered}}{\text{Tons/acre of class III, Conv.till.-}R_1\text{, i.e., 70.88}} \times 2.823(10^{-3}).$$

Table 7. (Continued)

Capability class	Management system	Erosion[c]	Sediment delivery ratios[a]			Concentration delivery ratios[b]			Add-on for gullying[d]	Sediment contribution/acre deliv.ratios		
			.20	.25	.30	.20	.25	.30		.20	.25	.30
		tons/acre				10-3 mg/1						
III	Conv.till.-R_1	70.88	14.126	17.720	21.264	13.109	16.387	19.663	2.823	15.932	19.210	22.486
	Conv.till-R_2	27.89	5.578	6.972	8.367	5.158	6.447	7.737	1.111	6.269	7.558	8.848
	Min.till.-R_1	32.86	6.572	8.215	9.858	6.077	7.596	9.116	1.309	7.386	8.905	10.425
	Min.till.-R_2	14.09	2.818	3.522	4.227	2.606	3.257	3.909	0.561	3.167	3.818	4.470
	Conv.till.+terrace-R1	1.10	0.220	0.275	0.330	0.203	0.254	0.305	-	0.203	0.254	0.305
	Conv.till.+terrace-R_2	0.43	0.086	0.107	0.129	0.080	0.099	0.119	-	0.080	0.099	0.119
	Min.till.+terrace-R_1	0.51	0.102	0.127	0.153	0.094	0.118	0.141	-	0.094	0.118	0.141
	Min.till.+terrace-R_2	0.22	0.044	0.055	0.066	0.041	0.051	0.061	-	0.041	0.051	0.061
	Perm.past.	0.69	0.138	0.172	0.207	0.128	0.160	0.191	-	0.128	0.160	0.191
IV	Conv.till.-R_1	177.77	35.554	44.442	53.331	32.877	41.096	49.315	7.080	39.957	48.176	56.395
	Conv.till.-R_2	69.94	13.988	17.485	20.982	12.935	16.168	19.402	2.786	15.721	18.954	22.188
	Min.till.-R_1	82.40	16.480	20.600	24.720	15.239	19.049	22.859	3.282	18.521	22.331	26.141
	Min.till.-R_2	35.34	7.068	8.835	10.602	6.536	8.170	9.804	1.408	7.944	9.578	11.212
	Conv.till.+terrace-R_1	2.60	0.520	0.650	0.780	0.481	0.601	0.721	-	0.481	0.601	0.721
	Conv.till.+terrace-R_2	1.02	0.204	0.255	0.306	0.189	0.236	0.283	-	0.189	0.236	0.283
	Min.till.+terrace-R_1	1.21	0.242	0.302	0.363	0.224	0.280	0.336	-	0.224	0.280	0.336
	Min.till.+terrace-R_2	0.52	0.104	0.130	0.156	0.096	0.120	0.144	-	0.096	0.120	0.144
	Perm.past.	2.59	0.518	0.647	0.777	0.479	0.599	0.718	-	0.479	0.599	0.718
VI	Perm.past.	5.01	1.002	1.252	1.503	0.927	1.158	1.390	-	0.927	1.158	1.390
VII	Perm.past	11.55	2.310	2.887	3.465	2.136	2.670	3.204	-	2.136	2.670	3.204
		Soil retention		D.R.=100						per structure		
II-VII	Gully structure[e]	3.053		3.053								-2.086 mg/1

[e]Taken from Table 33.

the amount of total phosphorus that is available, an available to total phosphorus ratio was developed (A/T ratio). This ratio is based on two Iowa studies which suggest that this ratio changes with the sediment concentration.[1] Using the two points obtained from the Iowa studies, a line was drawn on semi-log paper in Figure 4 to obtain A/T ratios for different sediment levels. Therefore, sediment is assumed to act as a buffer system for phosphorus with a smaller percent of total phosphorus being available at higher sediment levels than at lower levels. By reading the A/T ratios for various sediment levels from Figure 4 and applying them to the predicted phosphorus losses in Table 18, available phosphorus coefficients are obtained for each of the activities at alternative sediment levels. A summary of the available phosphorus coefficients for a sediment concentration of 10,000 mg/l are derived in Table 8a. The phosphorus coefficients for other sediment levels are calculated by the same procedure.

Water uses

The downstream water uses (next-uses) are used in determining the higher quality constraint levels. These uses are generated by a fictional city that is located at the lower end of the basin. It is assumed that the city demands about 2.5 million gallons per day (MGD) for municipal use. In addition, the in-stream uses considered are:

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[1] See Chapter IV, p. 44. It should also be pointed out that the exact ratio of available to total phosphorus and its relevance to water quality remains to be determined and verified.

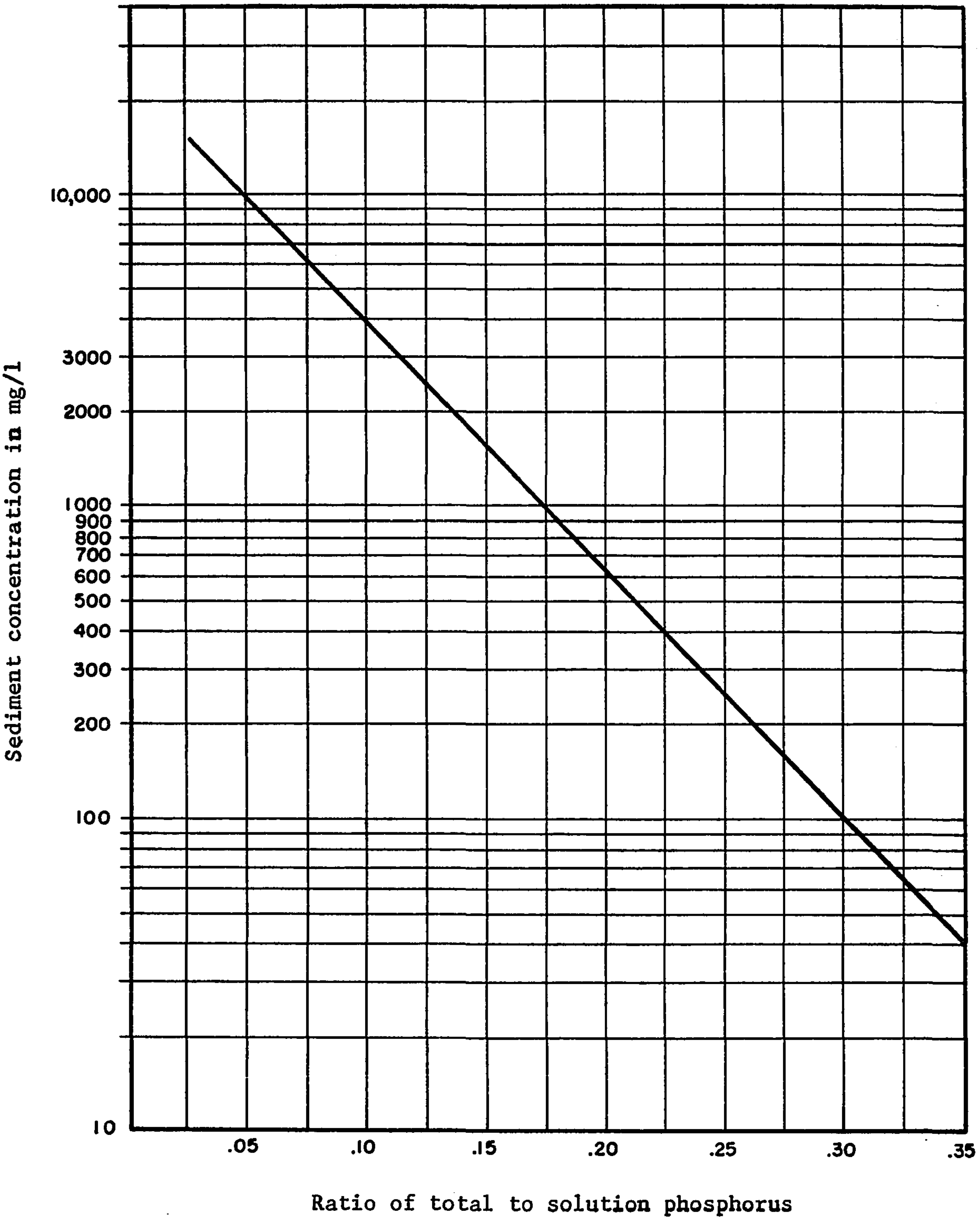

Figure 4. Ratio of solution phosphorus to total phosphorus at alternative sediment concentrations

1. Warm-water fish habitat
2. Contact recreation and aesthetics.

Quantitative quality levels for these uses in terms of suspended sediment or phosphorus are rarely specified. However, some desired values for turbidity[1] and phosphorus are available. Another problem is that turbidity is an optical property of water (9, p. 207), being the reduction in the intensity of light passing through water because of suspended matter. Therefore, equal turbidities may represent different concentrations because of different kinds and color of suspended matter. However, by specifying a particular suspended sediment, an estimation of suspended sediment from turbidity may be possible. Seay (85, p. 76) reports a linear relationship of 1 Jackson Turbidity Unit (JTU) = 1.5 mg/l from a study on Wyoming bentonite clay,[2] which is the conversion ratio used in this study.

With phosphorus, the major difficulty is with the different techniques used for measuring total phosphorus or available phosphorus. Therefore, unless specifically indicated, one is not certain what constitutes the total or available phosphorus concentrations reported. More specifically, sediment phosphorus has been of concern for only 2 to 3 years and methods to extract sediment phosphorus are quite variable. In this study, the solution or available phosphorus is the inorganic

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[1] It should be noted that "suspended sediment" and "turbidity" are not synonymous. Turbidity measures relate to all suspended matter and not only to suspended sediment. However, a study by Kunkle and Comer (61, p. 20) indicates that turbidity may be used to estimate suspended sediment concentrations.

[2] Montmorillonite is the main component of Wyoming bentonite which is also the dominant component of Marshall soils (85, p. 76).

Table 8a. Estimated available phosphorus coefficients with a sediment concentration of 10,000 mg/l.[a]

Capability class	Management system	Sediment constraint = 10,000 mg/l Delivery ratio=.20	 Delivery ratio=.25	 Delivery ratio=.30
		Phosphorus concentrations[b] 10^{-6} mg/l.		
I	Conv.till.-R_1	0.0528	0.0659	0.0792
	Conv.till.-R_2	0.0265	0.0331	0.0397
	Conv.till.+contour-R_1	0.0362	0.0452	0.0543
	Conv.till.+contour-R_2	0.0185	0.0231	0.0277
	Min.till.-R_1	0.0320	0.0400	0.0480
	Min.till.-R_2	0.0170	0.0213	0.0255
	Min.till.+contour-R_1	0.0221	0.0275	0.0331
	Min.till.+contour-R_2	0.0119	0.0148	0.0178
	Perm. past.	0.0018	0.0022	0.0028
II	Conv.till.-R_1	0.0987	0.1234	0.1481
	Conv.till.-R_2	0.0493	0.0617	0.0740
	Conv.till.+contour-R_1	0.0600	0.0751	0.0901
	Conv.till.+contour-R_2	0.0171	0.0214	0.0256
	Min.till.-R_1	0.0596	0.0745	0.0894
	Min.till.-R_2	0.0178	0.0222	0.0267
	Min.till.+contour-R_1	0.0363	0.0454	0.0545
	Min.till.+contour-R_2	0.0195	0.0244	0.0293
	Conv.till.+terrace-R_1	0.0057	0.0071	0.0086
	Conv.till.+terrace-R_2	0.0031	0.0038	0.0046
	Min.till.+terrace-R_1	0.0035	0.0043	0.0052
	Min.till.+terrace-R_2	0.0020	0.0025	0.0031
	Perm.past.	0.0036	0.0045	0.0054
III	Conv.till.-R_1	0.2808	0.3523	0.4227
	Conv.till.-R_2	0.1406	0.1757	0.2108
	Min.till.-R_1	0.1717	0.2146	0.2575
	Min.till.-R_2	0.0906	0.1132	0.1356
	Conv.till.+terrace-R_1	0.0112	0.0140	0.0169
	Conv.till.+terrace-R_2	0.0061	0.0076	0.0092
	Min.till.+terrace-R_1	0.0068	0.0085	0.0102
	Min.till.+terrace-R_2	0.0039	0.0049	0.0059
	Perm.past	0.0102	0.0127	0.0153

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[a] The same approach is used in computing phosphorus for the other sediment concentrations.

[b] Phosphorus concentrations were calculated from the following formula: soil delivered (tons/ac) x lbs. phosphorus/ton soil x .46235 x T/A ratio.

Table 8a. (Continued)

Capability class	Management system	Sediment constraint = 10,000 mg/l. Delivery ratio=.20	 Delivery ratio=.25	 Delivery ratio=.30
		Phosphorus concentrations[b] 10^{-6} mg/l.		
IV	Conv.till.-R_1	0.5096	0.6370	0.7644
	Conv.till.-R_2	0.2587	0.3234	0.3880
	Min.till.-R_1	0.3124	0.3905	0.4686
	Min.till.-R_2	0.1797	0.2247	0.2696
	Conv.till.+terrace-R_1	0.0197	0.0246	0.0296
	Conv.till.+terrace-R_2	0.0107	0.0134	0.0161
	Min.till.+terrace-R_1	0.0120	0.0149	0.0180
	Min.till.+terrace-R_2	0.0069	0.0087	0.0104
	Perm.past.	0.0242	0.0302	0.0363
VI	Perm.past.	0.0373	0.0466	0.0599
VII	Perm.past.	0.0641	0.0801	0.0961
II-			-62.5863	
VII	Gully structure[c]		-62.5863	

[c] Gully coefficient equals 1231.726 from Table 33 times T/A ratio for 10,000 mg/l. sediment concentration.

phosphorus measured in the filtrate filtered through Whatman No. 42 filter paper.[1] The sediment phosphorus used in determining the T/A ratio is based on the two studies mentioned earlier. However, one study used sodium bicarbonate ($NaHCO_3$) as the extract and the other uses an acid extract. While the two methods of extracting sediment phosphorus will not give the same results, for a PH = 6.0, the results can be expected to be similar.[2] Also, the acid extract will tend to remove more

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[1] Whatman No. 42 filter paper is that used in filtering samples for the two Iowa studies in determining solution or available phosphorus.

[2] In personal conversations with Dr. John J. Hanway, Agronomy Department, and Dr. Sheldon Kelman, Civil Engineering Department, it was also indicated that the acid extract will tend to remove more of the sediment phosphorus and particularly that of inorganic rather than organic origin. Thus, the difference would tend to be less with agricultural runoff than it would be for industrial wastes. Since only agricultural runoff is considered, the two methods are assumed to give comparable results for the purposes of this study.

of the sediment phosphorus and particularly that of chemical origin. Since only agricultural runoff is considered this difference would be minimized compared to industrial wastes. Therefore, it is assumed for purposes of this study that the two extract methods are comparable. Thus, the A/T ratio developed in Figure 4 is based on the above methods for determining available and sediment phosphorus.

The quality levels specified for water uses in the analysis are as follows:

1. Treatment of surface water supplies: suspended sediment 150 mg/l and available phosphorus (as P) .2 mg/l.[1]

2. Warm water fish habitat: suspended sediment 75 mg/l and available phosphorus (as P) .09 to .015.[2]

3. Primary contact recreation: suspended sediment 37.5[3] mg/l and phosphorus the same as for the fish habitat.

These values represent the more stringent quality levels desired by water uses and are part of the constraints used in the cost minimization program. The results of the program are discussed in the next section.

Programming Results

Because of the large difference between the stringent suspended sediment requirements and the computed average concentration of 10,544

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[1] Source: (85, p. 76 and 107, p. 24).

[2] Source: (107, p. 47 and 107, p. 53; plus 64, p. 20).

[3] Source: (85, p. 77).

mg/l in Table 34 of Appendix A, the suspended sediment constraints are parametrically changed. Beginning with 10,000 mg/l, the constrained levels are changed by increments of a thousand down to 1,000 mg/l, with the remaining levels set at 500, 250, 150, 75, and 37.5 mg/l. The last three constraints represent the desired levels of suspended sediment for the three selected uses.

Since phosphorus losses are directly related to sediment, phosphorus constraints were computed by applying the sediment load to the phosphorus-loss equation, using an E-value of 2, times the A/T ratio for that sediment load. These computed phosphorus constraints easily covered the range of phosphorus requirements specified for the water uses and are shown in Table 35 of Appendix A.

Using these constraints, the program was run initially to give solutions for only the suspended sediment levels and then with the phosphorus constraints added. These runs were made using three different delivery ratios and without "minimum tillage" activities in the final 6 runs. Solutions obtained in this manner made it possible to (1) derive total cost functions for the range of quality levels considered, (2) determine the impact of phosphorus constraints on total cost and at what level it becomes the constraining value, (3) observe the different activities which are present in the optimal solutions, and (4) observe the changes in the shadow price of the quality constraints (marginal cost) over the range of quality levels considered. Furthermore, the use of three different delivery ratios provides a sensitivity analysis of the program to changes in a physical parameter while the runs without "minimum tillage" indicate the impact of neglecting a modern technology.

In all, twelve runs were made on the computer. In presenting the results of these runs, the names assigned to the various programming activities are used. These names and their meanings are presented in Table 8b.

Upon observing all of the computer results, some general comments are possible. Land capability classes 1 and 2 were always in continuous row crops with terracing observed in only one of the solutions. Neither contouring nor the C-S-C-O-M-M rotation entered any of the optimal solutions. The phosphorus constraints added very little to the total cost of the sediment constraints, from 0 to just under 7 percent depending on the delivery ratio. Finally, the most stringent sediment and phosphorus quality levels were obtainable in all solutions. The first two observations are not too surprising in that continuous row crops, with little contouring or grass rotations, represent the prevailing practices in the area. The third observation might be expected if the apparent association between sediment and phosphorus is true. However, the four observations taken in total suggest two important conclusions. First, not only is it possible to meet the most stringent quality levels, but it can be done with continuous row crops occupying a substantial amount of the cropland. Second, by controlling sediment, a major step is also taken in controlling the phosphorus in runoff from agricultural lands.

In computer runs 1 through 3, only the sediment constraints for each of the three delivery ratios (DR) are considered. The initial

Table 8b. Description of names of programming activities

Activity name	Description
CONR1L1 ⋮ CONR1L4	Conventional tillage with a corn-corn-soybean (C-C-S) rotation on land classes 1 through 4
CONR2L1 ⋮ CONR2L4	Conventional tillage with a corn-soybean-corn-oats-meadow-meadow (C-S-C-O-M-M) rotation on land classes 1 through 4
MINR1L1 ⋮ MINR1L4	Minimum tillage with a C-C-S rotation on land classes 1 through 4
MINR2L1 ⋮ MINR2L4	Minimum tillage with a C-S-C-O-M-M rotation on land classes 1 through 4
CCONR1L1 ⋮ CCONR1L2	Conventional tillage with contouring and a C-C-S rotation on classes 1 and 2
CCONR2L1 ⋮ CCONR2L2	Conventional tillage with contouring and a C-S-C-O-M-M rotation on land classes 1 and 2
CMINR1L1 ⋮ CMINR1L2	Minimum tillage with contouring and a C-C-S rotation on land classes 1 and 2
CMINR2L1 ⋮ CMINR2L2	Minimum tillage with contouring and a C-S-C-O-M-M rotation on land classes 1 and 2
TCONR1L2 ⋮ TCONR1L4	Conventional tillage with terracing and a C-C-S rotation on land classes 2, 3, and 4
TCONR2L2 ⋮ TCONR2L4	Conventional tillage with terracing and a C-S-C-O-M-M rotation on land classes 2, 3, and 4.
TMINR1L2 ⋮ TMINR1L4	Minimum tillage with terracing and a C-C-S rotation on land classes 2, 3, and 4
TMINR2L2 ⋮ TMINR2L4	Minimum tillage with terracing and a C-S-C-O-M-M rotation on land classes 2, 3, and 4

Table 8b. (Continued)

Activity name	Description
Past L1 ¦ Past L7	Permanent pasture on land classes 1, 2, 3, 4, 5, and 7
Gully L2 ¦ Gully L7	Gully control structure on subclasses 2E, 3E, 4E, 6E, and 7E
UL	The upper limit of a particular activity
LUL	Indicates where an activity goes from its upper limit to less than the upper limit

quality level of 10,000 mg/l was obtained at zero cost with a DR of .20, i.e., capability classes 1 through 4 in MINR1 and 6 and 7 in PAST. With the .25 and .30 DR's, the program began to pasture class 4 land. As the sediment constraints were tightened, the program proceeded by pasturing all of class 4 land, building gully structures to the limit and was terracing class 3 land when achieving the most stringent constraint for all three DR's. The differences in the three solutions are (1) the increased total cost with the higher DR's and (2) the levels at which the various activities enter the optimal solution. Also, the tendency for the value of the dual activity, i.e., marginal cost or shadow price of the sediment constraints, to decrease at higher DR's, may seem surprising at first but is easily explained. At the higher DR's, the soil delivered per unit of activity is greater than at lower ratios. Therefore, in moving to a particular soil conserving practice, i.e., MINRI to PAST, the decrease in soil delivered per unit of activity is greater for the higher DR's. This results in the decreased marginal cost of constraints and explains why the total cost does not increase as much as one might expect at the higher DR's. The results of runs 1 through 3 are given in Tables 9, 10, and 11.

For runs 4, 5, and 6, the phosphorus constraints are added, but the results are almost identical with the first three runs. However, a few rather interesting observations should be discussed. First, the column of limiting phosphorus values indicates, based on the physical coefficients developed, at what level phosphorus becomes the constraining element for the various sediment levels. Thus, by comparing the sediment constraint and the corresponding limiting phosphorus value with the sediment and phosphorus requirements of a particular use, it is possible to determine which one is truly the limiting factor. For example, which factor is limiting for a warm water fish habitat with sediment and phosphorus requirements of 75 mg/l and .05 mg/l, respectively. Observing the sediment constraint and the corresponding limiting phosphorus values, it is apparent that sediment is the limiting factor with a D.R. of .20 while phosphorus is the limiting value for the two other DR's. Another interesting observation is the decrease in the value of the dual activity (marginal cost) for phosphorus constraints over a given range. This can be explained by the increasing A/T ratio as constraints become more stringent. This increasing A/T ratio increases the available phosphorus withheld per unit of a particular conservation activity, i.e., MINR1 to TMINR1, as the constraints become more stringent.

Table 9. Linear programming results: sediment constraints with a delivery ratio of .20 (solution 1)

Sediment objectives (mg/l)	Value of objective function (total cost in million dollars)	Value of dual activity for objective function (marginal cost) (thousand dollars)	Activities in the optimal solution					
			Land 1	Land 2	Land 3	Land 4	Land, 6,7	Gully control structures
10,000	-	-	MINR1-UL	MINR1-UL	MINR1-UL	MINR1-UL	PAST-UL	
9,000	-	-	↓	↓	↓	↓	↓	
8,000	0.264	0.30207	↓	↓	↓	↓-LUL PAST	↓	
7,000	0.566	0.30207	↓	↓	↓	↓	↓	
6,000	0.923	0.56141	↓	↓	↓	-UL	↓	Gully
5,000	1.484	0.56141	↓	↓	↓	↓	↓	↓
4,000	2.045	0.56141	↓	↓	↓	↓	↓	↓
3,000	2.607	0.56141	↓	↓	↓	↓	↓	↓
2,000	3.997	1.45365	↓	↓	LUL TMINR1	↓	↓	-UL
1,000	5.451	1.45365	↓	↓	↓ ↓	↓	↓	↓
500	6.178	1.45365	↓	↓	↓ ↓	↓	↓	↓
250	6.541	1.45365	↓	↓	↓ ↓	↓	↓	↓
150	6.687	1.45365	↓	↓	↓ ↓	↓	↓	↓
75	6.796	1.45365	↓	↓	↓ ↓	↓	↓	↓
37.5	6.850	1.45365	↓-UL	↓-UL	↓ ↓	↓-UL	↓ -UL	↓-UL

Table 10. Linear programming results: sediment constraints with a delivery ratio of .25 (solution 2)

Sediment objectives (mg/l)	Value of objective function (total cost in million dollars)	Value of dual activity for objective (marginal cost) (thousand $)	Activities in the optimal solution					
			Land 1	Land 2	Land 3	Land 4	Land 6,7	Gully control structures
10,000	0.176	0.25078	MINR1-UL	MINR1-UL	MINR1-UL	MINR1 PAST	PAST-UL	
9,000	0.427	0.25078	↓	↓	↓	↓ ↓	↓	
8,000	0.678	0.25078	↓	↓	↓	↓ ↓	↓	
7,000	1.082	0.56141	↓	↓	↓	↓ -UL	↓	Gully
6,000	1.643	0.56141	↓	↓	↓	↓	↓	↓
5,000	2.205	0.56141	↓	↓	↓	↓	↓	↓
4,000	2.903	1.20633	↓	↓	↓	↓	↓	↓
3,000	4.110	1.20633	↓	↓	↓ -LUL	TMINR1 ↓	↓	↓ -UL
2,000	5.316	1.20633	↓	↓	↓	↓ ↓	↓	↓
1,000	6.522	1.20633	↓	↓	↓	↓ ↓	↓	↓
500	7.125	1.20633	↓	↓	↓	↓ ↓	↓	↓
250	7.427	1.20633	↓	↓	↓	↓ ↓	↓	↓
150	7.548	1.20633	↓	↓	↓	↓ ↓	↓	↓
75	7.638	1.20633	↓	↓	↓	↓ ↓	↓	↓
37.5	7.683	1.20633	↓-UL	↓-UL	↓	↓ ↓-UL	↓-UL	↓-UL

Table 11. Linear programming results: sediment constraints with a delivery ratio of .30 (solution 3)

Sediment objectives (mg/l)	Value of objective function (total cost in million dollars)	Value of dual activity for objective (marginal cost) (thousand $)	Activities in the optimal solution						
			Land 1	Land 2	Land 3	Land 4		Land 6,7	Gully control structures
10,000	0.543	0.21437	MINR1-UL	MINR1-UL	MINR1-UL	MINR1	PAST	PAST-UL	
9,000	0.757	0.21437	↓	↓	↓	↓	↓	↓	
8,000	1.241	0.56141	↓	↓	↓	↓	-UL	↓	GULLY
7,000	1.803	0.56141	↓	↓	↓		↓	↓	↓
6,000	2.364	0.56141	↓	↓	↓		↓	↓	↓
5,000	3.159	1.03073	↓	↓	-LUL	TMINR1	↓	↓	-UL
4,000	4.190	1.03073	↓	↓	↓	↓	↓	↓	↓
3,000	5.220	1.03073	↓	↓	↓	↓	↓	↓	↓
2,000	6.251	1.03073	↓	↓	↓	↓	↓	↓	↓
1,000	7.282	1.03073	↓	↓	↓	↓	↓	↓	↓
500	7.797	1.03073	↓	↓	↓	↓	↓	↓	↓
250	8.055	1.03073	↓	↓	↓	↓	↓	↓	↓
150	8.156	1.03073	↓	↓	↓	↓	↓	↓	↓
75	8.235	1.03073	↓	↓	↓	↓	↓	↓	↓
37.5	8.274	1.03073	-UL	-UL	↓	↓	-UL	-UL	-UL

This increasing A/T ratio increases the available phosphorus withheld per unit of a particular conservation activity, i.e., MINR1 to TMINR1, as the constraints become more stringent. This in turn gives rise to the decreasing marginal cost of phosphorus constraints when a particular conservation activity is coming into the optimal solution. Furthermore, because of the increasing A/T ratios, one cannot say a priori that decreasing the suspended sediment concentration will also decrease the phosphorus concentration. This is observed by looking at the limiting phosphorus value column. Results of these three runs are summarized in Tables 12 through 14.

Runs 7, 8, and 9 are the same as runs 1 through 3 except for the deletion of all minimum tillage activities. The programming results of these runs show a substantial increase in total cost and alteration of land use patterns from that in runs 1, 2, and 3. For the initial 10,000 mg/l solution, all of class 4 land is in permanent pasture for each DR and gully control structures enter into the solution with the .20 and .25 DR's. As the more stringent requirements are achieved, the program converts class 3 land from CONR1 to PAST with the UL being reached only for the .30 DR. With the .30 DR, PAST on class 3 land reached the UL at the 3000 mg/l level. It was here that gully structures entered, but they never reached the UL. Programming results of runs 7 through 9 are shown in Tables 15 through 17.

In the final three runs, 10, 11, and 12, minimum tillage activities are again deleted but phosphorus constraints are added. The results of

Table 12. Linear programming results: sediment and phosphorus constraints with a delivery ratio of .20 (solution 4)

Objectives Sediment (mg/l)	Objectives Phosphorus (mg/l)	Limiting phosphorus values	Value of objective function (total cost million $)	Dual activity value for objectives: sediment (marginal cost) (thousand) $	Dual activity value for objectives: phosphorus (marginal cost) (million) $	Activities in the optimal solution: Land 1	Land 2	Land 3	Land 4	Land 6,7	Gully control structures
10,000	1.600	0.206	-	-	-	MINR1-UL	MINR1-UL	MINR1-UL	MINR1-UL	PAST-UL	
9,000	0.594	0.227	-	-	-						
8,000	0.586	0.235	0.264	0.30207	-				-LUL PAST		
7,000	0.580	0.243	0.566	0.30207	-						
6,000	0.555	0.243	0.923	0.56141	-				-UL		GULLY
5,000	0.522	0.222	1.484	0.56141	-						
4,000	0.476	0.193	2.045	0.56141	-						
3,000	0.413	0.155	2.607	0.56141	-						
2,000	0.328	0.122	3.997	1.45365	-			-LUL	TMINR1		-UL
1,000	0.209	0.076	5.451	1.45365	-						
500	0.127	0.044	6.178	1.45365	-						
250	0.075	0.024	6.541	1.45365	-						
150	0.049	0.014	6.687	1.45365	-						
75	0.029	0.005	6.796	1.45365	-						
37.5	0.016	0.0003	6.850	1.45365	-	-UL	-UL		-UL	-UL	-UL

Table 13. Linear programming results: sediment and phosphorus constraints with a delivery ratio of .25 (solution 5)

Objectives		Limiting phosphorus values	Value of objective function (total cost million $)	Dual activity value for objectives (marginal cost)		Activities in the optimal solution						
Sediment (mg/l)	Phosphorus (mg/l)			sediment (thousand) $	phosphorus (million) $	Land 1	Land 2	Land 3	Land 4	Land 6,7		Gully control structures
10,000	0.600	0.246	0.176	0.25078	-	MINR1-UL	MINR1-UL	MINR1-UL	MINR1	PAST	PAST-UL	
9,000	0.594	0.253	0.427	0.25078	-							
8,000	0.586	0.260	0.678	0.25078	-				↓			
7,000	0.580	0.262	1.082	0.56141	-					-UL		GULLY
6,000	0.555	0.246	1.643	0.56141	-							
5,000	0.522	0.226	2.205	0.56141	-							
4,000	0.476	0.201	2.093	1.20633	-			-LUL	TMINR1			-UL
3,000	0.413	0.179	4.110	1.20633	-							
2,000	0.328	0.149	5.316	1.20633	-							
1,000	0.209	0.108	6.522	1.20633	-							
500	0.127	0.082	7.125	1.20633	-							
250	0.075	0.067	7.427	1.20633	-							
150	0.049	0.061	7.548	-	9.24956							
75	0.029	0.059	7.638	-	8.16327							
37.5	0.016	0.059	7.638	-	7.34683	↓ -UL	↓-UL	↓	↓	↓UL	↓-UL	↓ -UL

Table 14. Linear programming results: sediment and phosphorus constraints with a delivery ratio of .30 (solution 6)

Objectives		Limiting phosphorus values	Value of objective function (total cost million $)	Dual activity value for objectives (marginal cost)		Activities in the optimal solution						
Sediment (mg/l)	Phosphorus			sediment (thousand) $	phosphorus (million) $	Land 1	Land 2	Land 3	Land 4	Land 6,7		Gully control structures
10,000	0.600	0.167	0.543	0.21437	-	MINR1-UL	MINR1-UL	MINR1-UL	MINR1	PAST	PAST-UL	
9,000	0.594	0.274	0.757	0.21437	-	↓	↓	↓	↓	↓	↓	
8,000	0.586	0.271	1.241	0.56141	-	↓	↓	↓		-UL	↓	GULLY
7,000	0.580	0.266	1.803	0.56141	-	↓	↓	↓		↓	↓	↓
6,000	0.555	0.250	2.364	0.56141	-	↓	↓	↓		↓	↓	↓
5,000	0.522	0.236	3.159	1.03073	-	↓	↓	-LUL	TMINR1	↓	↓	-UL
4,000	0.476	0.220	4.190	1.03073	-	↓	↓	↓	↓	↓	↓	↓
3,000	0.413	0.201	5.220	1.03073	-	↓	↓	↓	↓	↓	↓	↓
2,000	0.328	0.173	6.251	1.03073	-	↓	↓	↓	↓	↓	↓	↓
1,000	0.209	0.136	7.282	1.03073	-	↓	↓	↓	↓	↓	↓	↓
500	0.127	0.115	7.797	1.03073	-	↓	↓	↓	↓	↓	↓	↓
250	0.075	0.106	8.318	-	8.57258	↓	↓	↓	↓	↓	↓	↓
150	0.049	0.104	8.583	-	7.70909	↓	↓	↓	↓	↓	↓	↓
75	0.029	0.107	8.764	-	6.80359	↓	↓	↓	↓	↓	↓	↓
37.5	0.016	0.112	8.863	-	6.12363	↓-UL	↓-UL	↓	↓	↓-UL	↓-UL	↓ -UL

Table 15. Linear programming results: sediment constraints with a delivery ratio of .20 and without minimum tillage activities (solution 7)

Sediment objectives (mg/l)	Value of objective function (total cost in million dollars)	Value of dual activity for objective (marginal cost) (thousand $)	Activities in the optimal solution					
			Land 1	Land 2	Land 3	Land 4	Land 6,7	Gully control structures
10,000	12.325	0.56141	CONR1-UL	CONR1-UL	CONR1-UL	PAST-UL	PAST-UL	GULLY
9,000	13.074	0.75044	↓	↓	↓-LUL ↓PAST	↓	↓	↓-UL
8,000	13.825	0.75044						
7,000	14.575	0.75044						
6,000	15.326	0.75044						
5,000	16.076	0.75044						
4,000	16.827	0.75044						
3,000	17.577	0.75044						
2,000	18.327	0.75044						
1,000	19.078	0.75044						
500	19.453	0.75044						
250	19.641	0.75044						
150	19.716	0.75044						
75	19.772	0.75044						
37.5	19.800	0.75044	-UL	-UL		-UL	-UL	-UL

Table 16. Linear programming results: sediment constraints with a delivery ratio of .25, without minimum tillage activities (solution 8)

Sediment objectives (mg/l)	Value of objective function (total cost in million dollars)	Value of dual activity for objective (marginal cost) (thousand $)	Activities in the optimal solution						
			Land 1	Land 2	Land 3		Land 4	Land 6,7	Gully control structures
10,000	13.988	0.62257	CON-R1-UL	CON-R1-UL	CON-R1	PAST	PAST-UL	PAST-UL	GULLY-UL
9,000	14.610	0.62257							
8,000	15.233	0.62257							
7,000	15.855	0.62257							
6,000	16.478	0.62257							
5,000	17.100	0.62257							
4,000	17.723	0.62257							
3,000	18.246	0.62257							
2,000	18.968	0.62257							
1,000	19.591	0.62257							
500	19.902	0.62257							
250	20.058	0.62257							
150	20.120	0.62257							
75	20.167	0.62257							
37.5	20.190	0.62257	↓ -UL	↓ -UL	↓	↓	↓ -UL	↓ -UL	↓ -UL

Table 17. Linear programming results: sediment constraints with a delivery ratio of .30, without minimum tillage activities (solution 9)

Sediment objectives (mg/l)	Value of objective function (total cost in million dollars)	Value of dual activity for objective (marginal cost) (thousand $)	Activities in the optimal solution					
			Land 1	Land 2	Land 3	Land 4	Land 6,7	Gully control structures
10,000	15.099	0.53196	CON-R1-UL	CON-R1-UL	CON-R1 PAST	PAST-UL	PAST-UL	
9,000	15.631	0.53196	↓	↓	↓ ↓	↓	↓	
8,000	16.163	0.53196	↓	↓	↓ ↓	↓	↓	
7,000	16.695	0.53196	↓	↓	↓ ↓	↓	↓	
6,000	17.227	0.53196	↓	↓	↓ ↓	↓	↓	
5,000	17.759	0.53196	↓	↓	↓ ↓	↓	↓	
4,000	18.291	0.53196	↓	↓	↓ ↓	↓	↓	
3,000	18.824	0.56141	↓	↓	-UL	↓	↓	GULLY
2,000	19.385	0.56141	↓	↓	↓	↓	↓	↓
1,000	19.947	0.56141	↓	↓	↓	↓	↓	↓
500	20.228	0.56141	↓	↓	↓	↓	↓	↓
250	20.368	0.56141	↓	↓	↓	↓	↓	↓
150	20.424	0.56141	↓	↓	↓	↓	↓	↓
75	20.466	0.56141	↓	↓	↓	↓	↓	↓
37.5	20.487	0.56141	↓-UL	↓-UL	↓-UL	↓-UL	↓-UL	↓

these runs are similar to those obtained for runs 7 through 9. The only differences are (1) a slight increase in the total cost at the more stringent constraints for DR's of .25 and .30 and (2) a change in the activities present in the optimal solution with a .30 DR. Tables 18 through 20 provide a summary of the results from these runs.

The changes in land use and cost between runs 1, 2, and 3 indicate the sensitivity of an efficient set of control methods for various quality constraints to the different specified delivery ratios. Runs 4 through 6 give an indication of which factor is the limiting constraint and suggests that by controlling sediment, a major part of the phosphorus is also controlled. Finally, the comparison of the first 6 runs with the last 6 runs points out the dominance of minimum tillage activities in the program. This comparison also indicates the impact of neglecting to consider all possible technologies.

In summary, the cost minimization model provides a means for determining the total cost of achieving various specified quality levels and indicates the efficient set of control methods for each level. The benefits from improved quality levels and the framework for suggesting appropriate quality levels are the topics of the next chapter.

Table 18. Linear programming results: sediment and phosphorus constraints with delivery ratio of .20 and without minimum tillage activities (solution 10)

Objectives Sediment (mg/l)	Objectives Phosphorus (mg/l)	Limiting phosphorus values	Value of objective function (total cost million $)	Dual activity value for objectives (marginal cost) sediment (thousand) $	Dual activity value for objectives (marginal cost) phosphorus (million) $	Activities in the optimal solution Land 1	Land 2	Land 3	Land 4	Land 6,7	Gully control structures
10,000	0.600	0.166	12.325	0.56141	-	CON-R1-UL	CON-R1-UL	CON-R1-UL -LUL PAST	PAST-UL	PAST-UL	GULLY -UL
9,000	0.594	0.164	13.074	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
8,000	0.586	0.161	13.825	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
7,000	0.580	0.159	14.575	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
6,000	0.555	0.151	15.326	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
5, 00	0.522	0.140	16.076	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
4,000	0.476	0.126	16.827	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
3,000	0.413	0.107	17.577	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
2,000	0.328	0.080	18.327	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
1,000	0.209	0.042	19.078	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
500	0.127	0.015	19.453	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
250	0.075	0.003	19.641	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
150	0.049	-	10.716	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
75	0.029	-	19.772	0.75044	-	↓	↓	↓ ↓	↓	↓	↓
37.5	0.016	-	19.800	0.75044	-	↓-UL	↓-UL	↓ ↓	↓-UL	↓-UL	↓ -UL

Table 19. Linear programming results: sediment and phosphorus constraints with a delivery ratio of .25 without minimum tillage activities (solution 11)

Objectives Sediment (mg/l)	Objectives Phosphorus	Limiting phosphorus values	Value of objective function (total cost million $)	Dual activity value for objectives: sediment (marginal cost) (thousand) $	Dual activity value for objectives: phosphorus (marginal cost) (million) $	Activities in the optimal solution: Land 1	Land 2	Land 3	Land 4	Land 6,7	Gully control structures
10,000	0.600	0.186	13.988	0.62257	-	CON-R1-UL	CON-R1-UL	CON-R1 PAST	PAST-UL	PAST-UL	GULLY-UL
9,000	0.594	0.185	14.610	0.62257	-						
8,000	0.586	0.183	15.233	0.62257	-						
7,000	0.580	0.182	15.855	0.62257	-						
6,000	0.550	0.176	16.478	0.62257	-						
5,000	0.522	0.168	17.100	0.62257	-						
4,000	0.476	0.156	17.723	0.62257	-						
3,000	0.413	0.140	18.346	0.62257	-						
2,000	0.328	0.118	18.968	0.62257	-						
1,000	0.209	0.088	19.591	0.62257	-						
500	0.127	0.069	19.902	0.62257	-						
250	0.075	0.059	20.058	0.62257	-						
150	0.049	-	20.165	-	6.28178						
75	0.029	-	20.312	-	5.54413						
37.5	0.016	-	20.393	-	4.98969	↓-UL	↓-UL	↓ ↓	↓-UL	↓ -UL	↓-UL

Table 20. Linear programming results: sediment and phosphorus constraints with a delivery ratio of .30, without minimum tillage activities (solution 12)

Objectives		Limiting phosphorus values	Value of objective function (total cost million $)	Dual activity value for objectives (marginal cost)		Activities in the optimal solution					
Sediment (mg/l)	Phosphorus (mg/l)			sediment (thousand) $	phosphorus (million) $	Land 1	Land 2	Land 3	Land 4	Land 6,7	Gully control structures
10,000	0.600	0.240	15.099	0.53196	-	CONR1-UL	CONR1-UL	CONR1 PAST	PAST-UL	PAST-UL	
9,000	0.594	0.243	15.631	0.53196	-						
8,000	0.586	0.248	16.163	0.53196	-						
7,000	0.580	0.256	16.695	0.53196	-						
6,000	0.555	0.256	17.227	0.53196	-						
5,000	0.522	0.258	17.759	0.53196	-						
4,000	0.476	0.257	18.291	0.53196	-						
3,000	0.413	0.255	18.824	0.56141	-			-UL			GULLY
2,000	0.328	0.222	19.385	0.56141	-						
1,000	0.209	0.178	19.947	0.56141	-						
500	0.127	0.127	20.243	0.48605	0.59242			CONR1 -LUL			
250	0.075	-	20.610	-	5.82172		-LUL				-UL
150	0.049	-	20.913	-	9.53977			TCONR1 -UL			
75	0.029	-	21.137	-	8.41962						
37.5	0.016	-	21.260	-	7.57731	-UL		-UL	-UL	-UL	-UL

CHAPTER VI. WATER DEMANDS AND WATER QUALITY MANAGEMENT

The programming results presented in the preceding chapter illustrate that land use patterns can be an important factor in water quality. The costs associated with controlling quality through the various soil conserving practices were calculated as opportunity costs, i.e., the cost to the manager of using a practice which yields less than the highest possible alternative net return. While the costs of the programming results represent the least-cost system for achieving a given quality objective, this does not say that the objectives represent water quality levels which if achieved would maximize benefits. This suggests that basic to any optimum system of water quality management is the delineation of benefits and damages or what Kneese and Bower call the "damage cost function" (57, p. 109). The damage function is based on the functional relationship between the amount of waste constituents discharged and damages. In the case of water quality control practices, the "damage cost function" could be regarded as a "damage avoidance function", which would be the relationship between decreases in waste discharges and benefits. However, the inability to measure in economic terms the benefits and/or damages to uses from water quality alteration is one of the most exasperating aspects of quality management.

Measurement of Benefits

The premise of the study is that the uses or potential uses of water affected by agricultural uses are the prime concern in establishing quality levels. Thus, strategic to analyzing agriculture's role in water quality management are the identification of present and potential uses of that water supply and the water qualities tolerated by these uses. The point to realize is that water quality management must be related to the particular uses made or to be made of the affected water supply. Furthermore, in addition to the costs of control practices, the damages and/or benefits to particular uses associated with quality management practices need to be determined in suggesting relevant quality levels. Within this framework, water quality management is a user oriented concept with control practices being economically justified where incremental benefits exceed the increment costs.[1]

In attempting to measure the benefits of quality control practices to water uses, the two major difficulties appear to be: (1) quantifying the functional relationship between polluter control practices and the benefit to water uses and (2) placing a value on the benefits to recreational and aesthetic uses. Because of these difficulties, benefit analyses of quality control have generally been neglected and cost minimization has been the tool used in determining an optimum quality management system. However, there are at least four means of estimating the benefits of quality control practices to water users. First, assuming that the functional relationships can be identified, one can quantify certain measureable benefits, such as lower treatment costs

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[1] See Figure 1, page 47.

and reduced damages to equipment. Second, benefits to intangibles, such as recreation and aesthetics, can be estimated by imputed values from willingness to pay studies, cost of travel, total expenditures on a recreational experience, etc. Third, recreational benefits could be equated to the cost of particular control practices or to the cost of the least cost alternative project that would provide similar activities and quality features. Finally, some combination of the above techniques could be used to measure quality control benefits.

In this study, a combination of the first and third techniques is used in measuring the benefits from agricultural conservation practices. In specifying these benefits, one off-stream and two in-stream water demands are considered. It is assumed that these demands are generated by a city located at the lower end of the basin. The two in-stream uses are a warm water fish habitat and contact recreation. The single off-stream use is a municipal water supply plant which meets the city's domestic and industrial water demands. It should also be noted that the recreational demands could be met by the stream.

The location of the city at the southern end of the basin and the simplifying assumptions made in Chapter V reduce the basin to a fairly simple system. Specifically, the water course flows past the city at a constant volume with the suspended sediment and phosphorus concentrations of the water course dependent upon the agricultural land practices on the drainage area above the city. Since the assumption was made that all the sediment and phosphorus entering the stream are carried by it, the measurement of sediment and phosphorus concentrations are assumed to be made at the city. The cost of achieving various quality objectives at the point of use, i.e., the city, were presented in Chapter V. But in addition to the costs of achieving the higher quality objectives, there are also benefits to the municipal water supply plant in the form of reduced treatment costs.

In quantifying the reduced treatment costs, the physical relationships between certain quality constituents, i.e., some indices of quality, and the required treatment processes and chemicals must be specified. Frankel (35, p. 42) indicated that turbidity is an important raw water quality value in determining what type of treatment will be acceptable. In addition, Baxter (5, p. 182) stated that turbidity is one of the quality parameters that exerts a demonstrable effect on the chemical dosages used for treatment. Furthermore, turbidity is one of the quality parameters frequently measured by water supply treatment facilities (122, p. 6). This all suggests that turbidity is an important quality parameter in determining both the appropriate type of treatment and chemical dosages.[1] The implication of the above is that there is a physical relationship between the turbidity level of a raw

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[1] It should be pointed out that turbidity is only one of several quality parameters which affect the water treatment processes. Also, the type of turbidity that exists in the stream, i.e., colloidal or organic, affects the treatment process. Therefore, it cannot be stated that a certain type of treatment or chemical dosage is needed at any given level of turbidity. However, this does prevent turbidity from being used to establish a functional relationship between raw water quality of a given supply and the physical treatment provided.

water supply and the treatment of that supply. By specifying this relationship the treatment costs associated with the quality of the raw water supply, i.e., turbidity, can be determined. Therefore, for purposes of this study turbidity is the raw water quality parameter used in relating the incremental suspended sediment, i.e., turbidity, objectives[1] achieved in Chapter V to the reduced water treatment costs.

The reduced treatment costs associated with incremental reductions in suspended sediment were calculated in two steps. The first procedure was concerned with deriving the reduced construction costs associated with incremental changes in raw water quality, represented by changes in suspended sediment levels. While considerable cost information is available on the construction costs of various sized water treatment plants (35), little cost information is available on the construction cost of a given plant size for various raw water quality levels. However, Wanielista (122, p. 1) indicates that raw water quality should be given prime consideration in the design phase of water treatment facilities.

The objective of his study is to determine the sizes of the treatment units so that the overall cost of achieving a desired reduction in impurities is a minimum. In the model developed, the sizes of the treatment units are the decision variables used to satisfy the constraints. With the model, design criteria for the water treatment units

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[1] Although the quality objectives were specified in suspended sediment concentration, these can be converted to turbidity by the conversion ratio given in Chapter V.

and treatment costs can be obtained, once the raw water qualities, removal efficiencies and the cost of treatment units have been specified. To illustrate his point, Wanielista took a low quality, a medium quality, and a high quality supply source and obtained the minimum cost designs for the three different levels of input quality. The quality of the water supply source was based on five quality parameters of which turbidity is one. Although each of these parameters will have some impact on the design of treatment units, for purposes of this study it is assumed that turbidity alone is representative of the low quality and medium quality sources.[1] While this assumption may seem rather stringent, remember that the objective of the study is not precise estimates of cost and benefits of quality management, but rather a framework for water quality management.

In comparing the minimum cost designs for the three different sources of input quality, Wanielista (122, p. 90) indicated that approximately the same differences in construction costs can be realized for flow rates between one and twenty MGD. From these results he constructed the following construction cost equations for low and medium quality sources:

low quality water: $C = .62\ Q^{.57}$

medium quality water: $C = .52\ Q^{.57}$

where C = construction cost

Q = amount of water treated in MGD.

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[1] Only the low quality and medium quality supply sources are considered in the study because turbidity levels associated with the high quality source were not observed in this study.

Using these equations it was possible to calculate the construction costs associated with the low and medium quality sources. By subtracting the construction costs of the latter from the former the difference in construction cost for the two intake qualities was determined. The next step was to convert the turbidity associated with the two quality sources to suspended sediment concentrations, which is the quality parameter used in this study. Then the difference in the associated suspended sediment concentrations was obtained. By dividing the difference in construction costs by the difference in suspended sediment, it was possible to obtain the change in construction costs per mg/l change in suspended sediment. Using the construction cost equation for low quality water and change in construction cost per mg/l change in suspended sediment, it was possible to compute the construction costs associated with the various suspended sediment levels. The procedure described above is presented in Table 55 of Appendix B. The actual computed construction costs associated with the various suspended sediment levels are shown in Table 56 of Appendix B.

The other treatment costs associated with incremental reductions in suspended sediment are the chemical costs. In deriving the chemical costs, eight months of daily records on turbidity and chemical dosages were analyzed.[1] Using simple regression, results of the first

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[1] Eight months of daily records, from January 1, 1971 to September 7, 1971, were obtained from Joseph L. Gerit, Water Supply Engineer, for the Florence Treatment Plant, Metropolitan Utilities District of Omaha.

computer runs indicated that there was no relationship between turbidity levels and the amount of chemicals used.[1] Upon further investigation of the original data two observations on the characteristics of the data were made. First of all, it was noted that while the turbidity levels were very low, generally less than 5 JTU, in January and the first part of February, the chemical dosages tended to correspond with those used at turbidity levels of 20-40 JTU. This suggests that at the lower levels, turbidity was not a factor in the amount of chemical added. Because of this and combined with the fact that these low levels of turbidity were not considered in the study, these observations were discarded from the regression analysis. The other observation was that during the last part of February and in March excessive amounts of aluminum sulfate were used. This corresponded to Oulman's findings that during spring runoff excessive amounts of alum must be used to flocculate the colloidal matter in water (77). He concludes that the annual spring runoff problems are connected with the kind of colloidal matter washed into the river by surface runoff. Since this study does not examine spring runoff in relation to conservation practices, these observations were also excluded from the regression analysis. With these observations excluded, the regression of each of the four chemicals on turbidity was run again. Of these four chemicals only aluminum sulfate (alum) was shown to be significantly related to turbidity. The approximate least-squares

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[1] In the simple regression analysis, the chemicals investigated were aluminum sulfate, silicate of soda, carbon, and chlorine.

equation obtained was

$$Al = 46 + .138\ T$$

where Al is the lbs. of alum used per mgd and T is the JTU. Using this equation it was possible to calculate the amount of alum used at various turbidity or suspended sediment levels and the associated costs. The computation of these costs are found in Table 57 of the Appendix B.

By summing the estimated reduced construction and chemical costs, a value for reduced treatment costs associated with incremental reductions in suspended sediment was obtained. Furthermore, since a municipal water supply plant and recreation are assumed to be the only uses, a minimum value for recreation is obtained by subtracting the incremental treatment benefits from the incremental abatement costs. This corresponds to the method of equating the intangible benefits to cost of the control practices. A summary of these incremental costs and benefits with the corresponding suspended sediment levels are presented in Table 21. Having estimated the incremental costs and benefits of the water quality control practices, it is now possible to discuss its implication - concerning the question of what level of water quality?

What Level of Quality?

Throughout this study it has been emphasized that determination of effects from various levels of water quality is a critical component of water quality management, because waste constituents as they affect water quality management are objectionable only in relation to the intended uses of the water. Without the ability to recognize these effects, there is little or no basis for quality adjustments. However, recognizing that the quality of water does effect the water uses, the controlling question becomes, "What level of water quality should be maintained?"

Marginal analysis theory would tell us to invest in quality control practices up to the point where the additional cost of abatement practices equals the sum of additional benefits to the water uses. In formulating solutions within this theoretical framework, the problems of external diseconomies, difficulty of measuring benefits and the public nature of quality control renders the market mechanism incapable of expressing societal preferences. This is particularly true of quality control where large numbers of individuals and/or firms are usually involved, for then the possibility of voluntary action is remote.

The conclusion drawn from the above is that non-market arrangements for determining the level of quality must be devised. Therefore, the decisions concerning quality control would be made by institutional arrangements. Within this framework, it appears that economic analysis should analyze not one but several quality levels and means of achieving those levels. By estimating the costs and benefits of alternative quality levels and control methods, economic analysis provides the institutional decision unit with the probable impacts of various decisions. This type of information should lead to relevant and improved decisions by institutions.

Observing the incremental costs and benefits presented in Table 21 as an example, certain general conclusions are possible. First, the

Table 21. Summary of cost and benefits associated with incremental charges in suspended sediment levels

Suspended sediment level (mg/l)	Incremental control costs[b] (DR=.20)	Incremental control costs[b] (DR=.25)	Incremental treatment benefits[c] (i=.04) ($/mg/l)	Incremental treatment benefits[c] (i=.08) ($/mg/l)	Recreation and aesthetic benefits[a] (DR=.20) (i=.04)	Recreation and aesthetic benefits[a] (DR=.20) (i=.08)	Recreation and aesthetic benefits[a] (DR=.25) (i=.04)	Recreation and aesthetic benefits[a] (DR=.25) (i=.08)
10,000	-	-	-	-	-	-	-	-
9,000	0	251	2.84	3.28	0	0	248.16	247.72
8,000	302	251	↓	↓	299.16	298.72	248.16	247,72
7,000	302	561	↓	↓	299.16	298.72	558.16	557.72
6,000	561	561	↓	↓	558.16	557.72	↓	↓
5,000	561	561	↓	↓	↓	↓	↓	↓
4,000	561	1,206	↓	↓	↓	↓	1,203.16	1,202.72
3,000	561	1,206	↓	↓	↓	↓	↓	↓
2,000	1,454	↓	↓	↓	1,451.16	1,450.72	↓	↓
1,000	↓	↓	↓	↓	↓	↓	↓	↓
500	↓	↓	↓	↓	↓	↓	↓	↓
250	↓	↓	↓	↓	↓	↓	↓	↓
150	↓	↓	↓	↓	↓	↓	↓	↓
75	↓	↓	↓	↓	↓	↓	↓	↓
37.5	↓	↓	↓	↓	↓	↓	↓	↓

[a] Recreation benefits are the difference between increment control costs and incremental treatment benefits.

[b] Taken from Tables 9 and 10.

[c] Obtained by summing the treatment costs from Tables 56 and 57.

delivery ratio does not have a large impact on costs or benefits. Second, reduced suspended sediment levels provide a small reduction in treatment costs compared to abatement costs. Finally, for any quality improvements to be justified on an economic basis, either there must be a tremendous reuse of the water (80-400:1) or large recreational and esthetic benefits.

It should be pointed out that the results shown in Table 21 assume that the watercourse is the only source of supply for the municipal and recreational uses. However, it may be possible to obtain the municipal water supply from a ground water source. Indeed, Seay (85, Table 9, p. 94) indicates that the surface supply would be cheaper than the groundwater only if the suspended sediment is less than 150 mg/l. In addition it may be feasible to construct an off-stream impoundment to meet the recreational demands. Assume, for example, that one alternative was to construct a 200 acre recreational lake. Further, assume that the land drainage area to the lake area is small, i.e., less than 5:1, and that the entire area is in grass to minimize sedimentation problems. It is also assumed that the surface runoff from the drainage area is equal to the seepage losses. With these assumptions, the water demands of the recreational lake are based on a drought rainfall and evaporation corresponding to a probability of .10. Assuming a six-month operating period,[1] a ground water supply and a surface water

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[1] The six-month operating period is based on the fact that just under 80 per cent of the evaporation in the study area occurs between May and October (59).

supply source were developed for meeting the water demands of the 200 acre recreational lake. The physical components of the two lake systems and the corresponding cost are shown in Appendices A and B, Tables 36 and 58, respectively. Taking the recreational lake with the surface water supply, the estimated annual cost is about 23,500 dollars. Using this opportunity cost as a measure of recreational benefits, i.e., in this case the opportunity cost is the cost of constructing the recreational lake, one would conclude that on an economic basis no improvement in water quality is justified.[1] However, it does point out that a considerable cost savings may be possible by providing an alternative supply source , the obvious conclusion being that not only must alternative control practices be analyzed but also alternative supply sources must be considered in water quality management.

In summary, this analysis points up the physical, biological, and institutional problems in developing a basis or framework for managing the quality of a particular supply area. The scope and magnitude of these problems indicate that Water Quality Management must embrace a systematic search for and evaluation of the objectives and the possible alternatives to achieving the objectives. Developing such a water quality management system is the topic of the next section.

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[1] With the incremental cost of the lake added on to the treatment benefits, benefits are still considerably lower than the costs even at the high suspended sediment levels.

A Water Quality Management System

The objective of a water quality management system is to identify and maintain that quality which will foster the maximum net benefits from water uses. The development of such a comprehensive system of quality management for a water use area involves three interrelated questions. These three questions are:

1. What and for what level are waste constituents to be managed?
2. How to manage for the levels of waste constituents?
3. What is the appropriate institutional arrangement?

There are a number of assumptions involved in providing a system to answer these questions. With respect to the first question, it is assumed that the level of water quality is based on the level of constituents desired. This implies that public desires with respect to quality can be examined in terms of measurable constituents of water desired by water uses. It also implies that the waste constituents and desired constituents can be identified by water uses. Furthermore, it assumes that the transport mechanism which delivers these constituents from polluter to user can be quantified. With this information, it can be determined when a particular waste constituent is in conflict with those desired by a use downstream, thereby making them subject to removal. However, whether or not and to what extent this constituent should be removed depends on the associated costs and benefits.

The question of how much of a constituent and how to manage for it implies that a broad range of quality objectives and management practices to achieve the objectives exist. Furthermore, it is assumed that for any particular constituent affecting a water use, increments of quality improvement can be obtained by larger investment in control practices. This also assumes that the physical and cost relationships between management practices and quality constituents can be identified and quantified. Knowing the physical and cost coefficients for the alternative control practices, one can determine that control system which will minimize the cost of achieving a given objective. However, to determine the "proper" objective, the relationship between the benefits to water uses and control practices must be specified. With these relationships, it is possible to determine both the cost and benefits associated with each objective, thereby allowing us to select the appropriate objective.

However, given the premise that water quality takes on the aspects of a public good and that recreational benefits cannot be measured, the market mechanism is not capable of expressing the preferences of society. Thus, institutional arrangements for selecting and achieving the desired water quality must be devised. The "criteria" for evaluating the alternative institutional arrangements were presented in Chapter III. Seay (85) in using these criteria concludes that a regional or basin-wide management authority would best meet the criteria. This authority would then be responsible for presenting alternative quality goals and analyzing the costs and impacts of alternative means of achieving the goals.

Examination of the three questions above and the failure of the market system to express society's preferences suggests a framework for water quality management. The framework illustrated in Figure 5 would be useful in developing a systematic and integrated approach for quality control.

The framework contains three major obstacles and their associated determinants and needs in providing a remedy. The framework is developed from the discussion on water quality management to accommodate the results of the analysis. In summary, the basic parts of a comprehensive water quality management system are:

1. Establishment of a management authority
2. Identification of uses by waste constituents and desired constituents
3. Specification of physical linkage system
4. Specification of physical and cost coefficients of alternative management practices
5. Estimating the costs and benefits of alternative means of obtaining the various objectives
6. Implementation of the agreed-upon objective and system.

Obstacle	Determinants	Remedies
1. Conflict among uses in basin	External diseconomies	Establishment of a basin management authority (federal, state, and local).
2. What constituents are of concern with respect to water quality?	Physical linkage of water uses. Preceding use and quality desired by the next use(s).	Identification and measurement of waste constituents and desired constituents by uses. Quantification of the physical linkage system. Select alternative quality objectives.
3. How and how much of the constituent to manage for?	External diseconomies, external economies and lack of measurement.	Identification of possible alternative management practices. Specification of physical and cost coefficients. Estimation of costs and benefits. Choice and implementation of a management system.

Figure 5. A framework for water quality management

CHAPTER VII. SUMMARY AND CONCLUSIONS

Having applied the cost minimization model and suggested a framework for quality management, it is now possible to assess the study in terms of achievements, implications, and limitations. Upon doing this, it will be possible to suggest some applications of the study and additional research.

Achievement of Objectives

The first objective was to develop a systematic and integrated system for establishing the level of quality for a given water supply. To obtain this objective, it was necessary to identify polluters and water uses by quality constituents, quantify the physical linkage of uses, and specify the alternative techniques for diminishing the conflicting quality constituents of the supply. Up to this point, the system is entirely a physical system. The second objective was to formulate a method to estimate the least-cost means of achieving a particular level of quality. To answer the question of which quality control techniques, i.e., least-cost techniques, should be employed, the physical and cost coefficients for each technique must be specified. The framework and model for such a system was presented in Chapter IV. As a general analytical approach, the system portrayed is conceptually sound. However, because of the many simplifying assumptions presented in quantifying the physical linkage of uses, the system is severely lacking in reality. This lack of reality is primarily the result of the limited data and understanding of the physical relationships in a water linkage system. While the system lacks in reality, it does point up those areas where additional research and data are needed. The conclusion, which tends to agree with the opinion of others (124, p. 2), is that analytical techniques have outstripped data so that emphasis must now be shifted to improving data inputs.

The next objective was the application of the analytical approach to a water supply area. Application of the model provided the least-cost techniques for resolving quality conflicts of water uses by manipulating the quality of the supply. The computed costs and the control techniques used are shown in Tables 9-20 of Chapter V. Remember that three different delivery ratios are used and that the phosphorus coefficients change with the suspended sediment level. Recall that the first three solutions were for suspended sediment constraints only, while the next three solutions contained both sediment and phosphorus constraints. The results of these six runs show minimum tillage completely dominating the other tillage methods. The results also indicate that there is a small increase in cost associated with the higher delivery ratios and that phosphorus becomes a limiting factor only at the more stringent constraint levels. The program also shows that MIN-R1, TMIN-R1, PAST, and Gully are the only activities in the least-cost solution. Since R1 signifies continuous row crops, the only cropping systems in the least-cost solutions are row crops and pasture. Furthermore, since minimum tillage had a zero opportunity cost, the cost of the program consisted of the opportunity cost of pasture on Class IV land and the construction cost of terraces and gully structures.

In the final six solutions, the objectives were the same as in the first six solutions, the only difference being that all minimum tillage activities were deleted. While it was possible to meet all the quality objectives, there was a considerable increase in cost. Also, a considerable change occurred in land use patterns with pasture occurring on a considerable amount of the Class III land. However, even with these changes, continuous row crops and pasture are the only two cropping systems in the least-cost solutions.

The obvious conclusion is that minimum tillage with continuous row crops is the dominant land use. This becomes apparent when one observes that not only does minimum tillage yield the highest net return, it also is an effective erosion control method. For example, upon looking at the estimated soil losses by activities and capability classes in Table 7, the soil loss from a meadow rotation with conventional tillage is similar to that from continuous row crops with minimum tillage. Perhaps of more interest is the practical use of the analytical framework. This assumes, of course, that the erosion and transport mechanism are understood and quantifiable. Knowing this, the control authority could set erosion standards that would correspond to stream quality levels, permitting individuals to select the needed control practices. Furthermore, to aid individuals in selection and to ease the policing of the system, the combinations of crops, tillage methods, and control practices that would meet erosion standards for the various capability classes could be specified. For example, Iowa has legislated six conservancy districts in Iowa watersheds to provide for the adoption of soil erosion standards. It appears that this approach would be useful in selecting erosion standards by capability class and in indicating the various land use systems which are capable of achieving these standards.

Returning to the first objective which is concerned with developing a basis for setting the quality level of a water supply: while the above framework provided the least-cost means of achieving a given quality objective, it in no way indicated which of these objectives should be adopted. The basic premise is that water quality is controlled not for the sake of quality but for the purpose of fostering the multiple uses of that supply. In this light, economic theory would tell us to improve water quality as long as additional benefits are greater than additional costs. Of course, this assumes that in addition to the costs, the benefits associated with quality improvements can also be measured. Because of the problems in specifying the physical relationships between water quality and its impact on water uses and of placing a value on intangibles, such as recreation and esthetics, this part of the analysis is either ignored or done in a cursory fashion. In Chapter VI, an attempt is made to estimate the reduced treatment costs associated with the improved quality of the supply source. While the approach is conceptually sound, the assumption of one quality parameter and a linear relationship between intake quality and treatment costs severely limit its reality. This again is felt to be due primarily to the lack of data and the physical relationship between source quality and water uses. However, it does suggest a means for estimating the benefits of improved quality for a number of water uses. But all such benefits cannot be quantified, therefore the final solution on the level of quality must be decided by the institutions representing the public.

The fourth objective was to suggest the major physical, economic, and institutional aspects of a water quality management system. Such a framework was specified in Chapter VI and was the outgrowth of the first three objectives. Therefore, while the framework is conceptually sound, it is subject to the limitations of the first three objectives.

The final objective is to suggest additional research needs, which become apparent from the evaluation of the study. The suggested areas where additional research is needed are presented in the last section of this chapter. In conclusion, the framework suggested provides a systematic and integrated means for identifying water quality conflicts and for resolving the conflicts in the least-cost manner. However, it does not provide a sound basis for setting the optimal level of water quality. In addition, the application of the framework points up the limitations of the study and the related data needs.

Study Limitations and Implications

In review, the major limitations of the study are:

1. The use of long-term average flow, soil, and phosphorus losses, to depict the hydrologic system. However, precipitation and the related erosion and streamflow do not occur in long-term averages. This suggests that research relating individual rainstorms with stream quality is needed to provide more realism to the results.
2. The assumption: homogenous production units and a single municipality make the system more manageable, but clearly a real world system will be more complex.
3. The consideration of only two independent quality parameters limits the applicability of the results. Few streams would contain only two conflicting quality parameters. Furthermore, it is highly unlikely that there is not some type of relationship between the quality parameters in terms of their impact on water uses. This suggests that additional data is needed on the quality requirements of uses and the interrelationships between quality parameters.
4. Finally, the use of turbidity as the only factor affecting treatments costs severely limits the results. As was indicated in the regression analysis in Chapter VI, not only the level of turbidity but also the solids which it is composed of

greatly affect the chemical dosage and the resultant cost. However, as an approach to measuring benefits, it is an improvement on the opportunity cost approach.

The study objectives and the approach used in striving to achieve them suggest several implications of quality management. These are presented and discussed below.

1. In determining which quality parameters may be conflicting, the impacts and desires of water uses must be identified by quality parameters. Therefore, water quality management must be based on the uses of that particular water supply which are spatially oriented. This suggests that universal quality levels are meaningless in that quality requirements will vary from area to area.
2. In determining when the above quality parameters are actually conflicting, a physical system linking the potential pollutant to the watercourse and to the point of impact must be specified. Furthermore, when the quality parameters of water uses and the supply source are in conflict, various techniques for resolving these conflicts can be specified. However, because of the complexity of the physical system, experts from other disciplines must be relied upon to provide data on the physical and technical aspects of the system.
3. This points up the third implication, which is the necessity for interdisciplinary research groups to participate jointly in this type of study. Ideally, the research would be conducted

by a research team composed of members from various disciplines. For this group to function properly, each member would have to become familiar with the basic concepts and terms of the other disciplines.

4. The costs of achieving various quality objectives may be calculated through parametric linear programming. While a comparable means for estimating benefits is not available, the "shadow prices" of the various programming objectives could be used to indicate the minimum benefits needed to justify such a quality level. Furthermore, it appears that regression techniques could be quite useful in quantifying benefits from quality improvement to several water uses.
5. Finally, the non-market aspects of water quality management limits the applicability of traditional cost-benefit analysis for allocating resources. Therefore, some type of institutional arrangement must be established to perform allocative functions in the use area. Furthermore, since land use can be an important factor in water quality, some type of land use policy with implementing programs appears warranted.

Research Needs

Research needs in the area of quality management are numerous and urgent. One needs only to look at the number of simplifying assumptions underlying the framework for quality management developed in this study to reach this conclusion. These simplifying assumptions indicate the lack of knowledge and suggest several feasible avenues of research for the near future. These research avenues appear to consist of three major groups: (1) determination of physical relationships, (2) estimation of costs and benefits, and (3) development of institutional arrangements.

In the first group, we are concerned with providing the data and physical relationships needed in improving the application of our model to provide answers to current questions on water quality management. Of special interest here is the physical relationship between environmental factors, i.e., number of species of algae, fish, etc., and a number of quality parameters. In addition, the relationship between a set of quality and environmental factors and water uses is needed. If these relationships were known, an index number representing various sets of quality parameters could be used in modeling a system considering a large number of quality parameters.

With respect to agricultural pollutants, the main concern for data needs appears to be not with the soil loss per se but with its associated nutrients and chemicals. Therefore, the prime target for research here is determining the relationship of variables including time of application, location of application, amount applied, duration of application, type of chemical applied, and land practices with the losses of these potential pollutants. These types of relationships are essential in suggesting regulations or controls for fertilizers, chemicals, and/or erosion.

The second area of needed research is the quantification of damages inflicted by various pollutants. Of prime concern here are (1) the development of a monitoring system to specify pollutant levels in terms of the above variables and (2) the development of a methodology for estimating damages and benefits from water quality control. Both damages and benefits are needed for controlling water quality at a given level may be beneficial to one use and inflict damages on another use. Regression techniques appear to have promise here in terms of specifying relationships between water quality and the associated costs for municipal and industrial uses.

The third area of research is perhaps the most difficult and most needed in terms of providing appropriate management systems. The major research areas here are how the various institutional regulations affect the costs of abatement practices, who bears the cost (distributional impacts), and an environmental management system that considers resource quality as an interrelated system. Possibilities include prescriptive criteria and licensing of applicators. Such measures might well be based upon a monitoring system for providing relationships and needs in terms of the variable specified above in connection with physical research needs.

Conclusions

The framework presented in this study suggests the three dimensional aspect and data needs of a comprehensive quality management program. The limitations of current measures, available information, and corresponding research needs were discussed earlier in the chapter. Probably the most significant departure from reality was the simplifying assumptions in modeling the hydrologic system and the consideration of only two quality constituents as parameters. In particular, sediment and phosphorus were the parameters selected because sediment appears to constitute the largest single pollutant, and phosphorus is considered as the factor most likely to be limiting in an aquatic system. The simplifying assumptions underlying the water quality management model developed indicates the extensive research involved in more accurately depicting the hydrologic system and thereby improving the applicability of the model.

Finally, the results of the analysis suggests the following: (1) that the water quality objectives for a given water supply area should be based on the water quality use requirements of that supply; (2) that the analytical framework presented has practical application in specifying quality levels and appropriate control practices; and (3) that some form of basin-wide authority is necessary for achieving and maintaining quality levels as an inherent component of quality management. Furthermore, one of the authority's responsibilities might be to establish or to conform with a comprehensive land use policy.

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ACKNOWLEDGEMENTS

The author wishes to express his appreciation to:

John F. Timmons, his major professor, for counsel and guidance throughout his study at Iowa State University and particularly during the thesis preparation. His enthusiasm and broad knowledge of environmental problems were of great help in bringing the research to bear on the problems of water quality management.

Professors Bachmann, Baumann, Hopkins, Moldenhauer, and Starleaf, who served ably as members of his graduate committee. Their constant willingness and ability to explain the details of their specialties to me improved the study illimitably.

Professor Merwin D. Dougal, whose assistance with technical aspects, was especially helpful.

Members of the Iowa Natural Resources Council, W. A. Myes, Chevron Chemical Company, Des Moines, Iowa, and John Maddy, Soil Conservation Service, Des Moines, Iowa, for their cooperation in supplying information and data.

Mrs. Donna Johnson, who typed the first draft and assisted with the administrative details.

The Department of Economics at Iowa State University and the Iowa State Water Resources Research Institute for financial support which made graduate study and the completion of this thesis possible.

Ron Winterboer, for his assistance with programming problems.

Phil Spies and Herb Schellenberg, fellow graduate students, who endured and assisted me in answering my questions. Also, to Herb Schellenberg for his assistance in proof reading the final draft.

My wife, Carol, for her encouragement and patience, assistance with the proof reading of the many drafts, and particularly for taking an unequal share of the major responsibility of raising our daughter and son, Teresa and Dennis, during my graduate study.

APPENDIX A: PHYSICAL AND TECHNICAL DATA

Table 22. Development of cropping-management factor (C) for C-C-S rotation with conventional tillage[a]

(1) Operation[b]	(2) Date	(3) Readings Curve No. 13	(4) Crop stage	(5) EI in period %	(6) Soil-loss ratio	(7) Columns 5 x 6	(8) C-value	(9) Rotation average
<u>Corn after soybeans</u>								
TP-corn	4/15	5[c]	S4	--	--	--	--	--
P-corn	5/1	7	F	2	43[d]	.0086	--	--
	6/1	19	C1	12	76	.0912	--	--
	7/1	47	C2	28	60	.1680	--	--
HV-corn	10/20	97	C3	50	31	.1550	--	--
TP-corn	4/15	105	C4	8	36	.0288	.4516	--
<u>Corn after corn</u>								
TP-corn	4/15	5[c]	C4	--	--	--	--	--
P-corn	5/1	7	F	2	36[e]	.0072	--	--
	6/1	19	C1	12	63	.0756	--	--
	7/1	47	C2	28	50	.1400	--	--
HV-corn	10/20	97	C3	50	26	.1300		
TP-beans	4/25	107	C4	10	30	.0300	.3828	
<u>Soybeans after corn</u>								
TP-beans	4/25	6[c]	C4	--	--	--	--	--
P-beans	5/15	12	F	6	36[f]	.0216	--	--
	6/15	33	S1	21	63	.1323	--	--
	7/15	57	S2	24	50	.1200	--	--
1-N-beans	10/5	94	S3	37	26	.0962	--	--
TP-corn	4/15	105	S4	11	30	.0330	.4031	.4125 .4125

---

[a] This table follows the example given in (128, Table 5, p. 35).

[b] The symbols: TP=turn plow; P=plant; and HV=harvest.

[c] Value from readings curve no. 13 in (128, Figure 11, pp. 82-83).

[d] Values taken from (128, Table 2, line 36, p. 12 x 120%). An adjustment as indicated by (73) for increased soil losses with corn following soybeans.

[e] Values taken from (128, Table 2, line 36, p. 12) as representative of soil-losses from continuous corn.

[f] Values for soil-loss ratio from soybeans are assumed to be the same as for continuous corn.

Table 23. Development of cropping-management factor (C) for C-C-S rotation with minimum tillage[a]

(1) Operation[b]	(2) Date	(3) Readings Curve 13[c] (%)	(4) Crop stage	(5) EI in period (%)	(6) Soil-loss ratio (%)	(7) Cols. 5 x 6	(8) C-value
Corn after soybeans - residue: 1500 - 2000 lb/ac							
P-corn	5/1	7[c]	54	--	--	--	--
	6/1	19	C1	12	48[d]	.0576	--
	7/1	47	C2	28	38	.1064	--
HV-corn	10/20	97	C3	50	22	.1100	--
P-corn	5/1	107	C4	10	30	.0300	.3040
Corn after corn - residue: 3000 - 4000 lb/ac							
P-corn	5/1	7[c]	C4	--	--	--	--
	6/1	19	C1	12	20[e]	.0240	--
	7/1	47	C2	28	16	.0448	--
HV-corn	10/20	97	C3	50	9	.0450	--
P-beans	5/15	112	C4	15	15	.0225	.1363
Soybeans after corn - residue: 3000 - 4000 lb/ac							
P-beans	5/15	12[c]	C4	--	--	--	--
	6/15	33	S1	21	20[f]	.0420	--
	7/15	57	S2	24	16	.0384	--
HV-beans	10/5	94	S3	37	9	.0333	--
P-corn	5/1	107	S4	13	15	.0195	.1332
							.1912

[a] This table follows the example given in (128, Table 5, p. 35).

[b] The symbols: P=plant; and HV=harvest.

[c] Values taken from reading curve no. 13 in (128, Figure 11, p. 24).

[d] Values taken from (127, Table 1, residue at 1500 lb., p. 52) x 120%. An adjustment as indicated by (73) for increased soil loss with corn following soybeans.

[e] Values taken from (127, Table 1, residue at 3000 lb., p. 52) for corn following corn.

[f] Values for soil-loss ratio from soybeans assumed to be the same as for corn after corn.

Table 24. Development of cropping-management factor (C) for C-S-C-O-M-M rotation with conventional tillage[a]

(1) Operations[b]	(2) Date	(3) Readings curve 13 (%)	(4) Crop stage period	(5) EI in period (%)	(6) Soil-loss ratio (%)	(7) Cols. 5 x 6	(8) C-value
Corn after meadow							
TP-corn	4/10	4[c]	M	--	--	--	--
P-corn	5/1	7	F	3	8[d]	.0024	--
	6/1	19	C1	12	25	.0300	--
	7/1	47	C2	28	17	.0476	--
HV-corn	10/20	97	C3	50	10	.0500	--
TP-beans	4/25	107	C4	10	15	.0150	.1450
Soybeans after corn							
TP-beans	4/25	6[c]	C4	--	--	--	--
P-beans	5/15	12	F	6	.25[e]	.0150	--
	6/15	33	S1	21	48	.1008	--
	7/15	57	S2	24	37	.0888	--
HV-beans	10/5	94	S3	37	20	.0740	--
TP-corn	4/15	105	S4	11	24	.0264	.3050

---

[a] This table follows the example given in (128, Table 5, p. 35).

[b] The symbols: TP = turn plow; P=plant; D=disk; and HV=harvest.

[c] Values from reading curve no. 13 in (128, Figure 11, p. 24).

[d] Values taken from (128, Table 2, line 1, p. 12) as representative of first year corn after meadow.

[e] Values taken from (128, Table 2, line 13, p. 12) as representative of second year corn (soil-loss ratios for soybeans assumed same as for corn) after meadow.

Table 24. (Continued)

(1) Operations[b]	(2) Date	(3) Readings curve 13 (%)	(4) Crop stage period	(5) EI in period (%)	(6) Soil-loss ratio (%)	(7) Cols. 5 x 6	(8) C-value
Corn after soybeans							
TP-corn	4/15	5[c]	S4	--	--	--	--
P-corn	5/1	7	F	2	43[f]	.0086	--
	6/1	19	C1	12	76	.0912	--
	7/1	47	C2	28	60	.1680	--
HV-corn	10/20	97	C3	50	31	.1550	--
D-oats	4/1	103	C4	6	36	.0216	.4444
Oats after corn							
D-oats	4/1	3[c]	C4	--	--	--	--
A-oats	4/5	4	F	1	30[g]	.0030	--
	5/5	8	01	4	32[h]	.0128	--
	6/5	23	02	15	19	.0285	--
HV-oats	7/15	57	03	34	5	.0170	--
	9/15	88	04	31	3	.0093	.0706
Meadow after oats (2 yrs of meadow)							
	9/15	288	M	200	.4[i]	.0080	--
TP-corn	4/10	304	M	16	.4	.0006	.0086
							.1623

---

[f] Values taken from (128, Table 2, line 36, p. 12) as representative of continuous corn x 120%. An adjustment as indicated by (73) for increased soil losses with corn following soybeans.

[g] Value for soil-loss ratio of disked corn stubble is assumed to be the same as for corn in crop-state 4.

[h] Values taken from (128, Table 2, line 93, p. 13) as representative of oats following 2nd or 3rd year corn after meadow.

[i] Value taken from (128, Table 2, line 120, p. 14) as representative of mixed grass-legume meadow.

Table 25. Development of cropping-management factor (C) for C-S-C-O-M-M tillage[a]

(1) Operation[b]	(2) Date	(3) Readings curve 13	(4) Crop stage	(5) EI in period	(6) Soil-loss ratio	(7) Cols. 5 x 6	(8) C-value
Corn after meadow							
P-corn	5/1	7[c]	M	--	--	--	--
	6/1	19	C1	12	2[d]	.0024	--
	7/1	47	C2	28	2	.0056	--
HV-corn	10/20	97	C3	50	2	.0100	--
P-beans	5/15	112	C4	15	1	.0015	.0195
Soybeans after corn residue:	3000 - 4000 lb/ac						
P-beans	5/15	12[c]	C4	--	--	---	--
	6/15	33	S1	21	14[e]	.0294	--
	7/15	57	S2	24	11	.0264	--
HV-beans	10/5	94	S3	37	8	.0296	--
P-C	5/1	107	S4	13	12	.0156	.1010

---

[a] This table follows the example given in (128, Table 5, p. 35).

[b] The symbols: TP:P=Turn plow and plant; D=disk; P=plant; and HV=harvest.

[c] Values from reading curve no. 13 (128, Figure 11, p. 24).

[d] Values from personal conversation with John Maddy, conservation agronomist, SCS, Des Moines, Iowa, 6-10-71, as representative of first year corn after meadow with plow-plant practice.

[e] Values taken from (127, Table 1, residue of 3000 lb, p. 52) x .70, .75 and .80 respectively. This is an adjustment for decreased soil loss indicated by (128, line 19 compared to line 36) for second year corn (soybean soil-loss ratio assumed same as for corn) following meadow.

Table 25. (Continued)

(1) Operation[b]	(2) Date	(3) Readings curve 13	(4) Crop stage	(5) EI in period	(6) Soil-loss ratio	(7) Cols. 5 x 6	(8) C-value
Corn after soybeans - residue: 1500 - 2000 lb/ac							
P-corn	5/1	7[c]	S4	--	--	--	--
	6/1	19	C1	12	48[f]	.0576	--
	7/1	47	C2	28	38	.1064	--
HV-	10/20	97	C3	50	22	.1100	--
D-oats	4/1	103	C4	6	30	.0180	.2920
Oats after corn							
D-oats	4/1	3[c]	C4	--	--	--	--
P-oats	4/5	4	C4	1	30[g]	.0030	--
	5/5	8	01	4	32[h]	.0128	--
	6/5	23	02	15	19	.0285	--
HV-oats	7/15	57	03	34	5	.0170	--
	9/15	88	04	31	3	.0093	.0706
Meadow after oats (2 yrs of meadow)							
	9/15	288[c]	M	200	.4[i]	.0080	--
TP:P-corn	5/1	307	M	19	.4	.0008	.0088
							.0820

[f] Values taken from (127, Table 1, residue of 1500 lb, p. 52) x 120%. An adjusted as indicated by (73) for increased soil losses from corn following soybeans.

[g] Value for soil-loss ratio of disked corn stubble is assumed to be same as for corn in corn stage 4.

[h] Value taken from (128, Table 2, line 93, p. 13) as representative of oats following 2nd or 3rd year corn after meadow.

[i] Value from (128, Table 2, line 120, p. 14) as representative of mixed grass-legume meadow.

Table 26. Computed erosion rates by land capability class for C-C-S rotation under two tillage systems

Capability class	Slope length (ft)	S slope gradient (%)	R	K	LS	P	C-value (Rotation av.)	A=RKLSPC (rotation av. tons/ac.)
Conventional tillage								
I	300	1.0	168	.33	.236598	1	.4125[a]	5.4108
II	300	3.5	168	.33	.614185	1	.4125	14.0458
III	600	9.5	168	.33	3.099584	1	.4125	70.8844
IV	600	17.0	168	.33	7.773211	1	.4125	177.7655
Minimum tillage								
I	same as above						.1912[b]	2.5080
II							.1912	6.5104
III							.1912	32.8560
IV							.1912	82.3970

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[a] From Table 22.

[b] From Table 23.

Table 27. Computed erosion rates by land capability class for C-S-C-O-M-M rotation under two tillage systems

Capability class	Slope length (ft.)	Slope gradient (%)	R	K	LS	P	C-value (rotation av.)	A=RKLSPC (rotation av. ton/ac)
Conventional tillage								
I	300	1.0	168	.33	.236598	1	.1623[a]	2.1289
II	300	3.5	168	.33	.614185	1	.1623	5.5264
III	600	9.5	168	.33	3.099584	1	.1623	27.8898
IV	600	17.0	168	.33	7.773211	1	.1623	69.9427
Minimum tillage								
I							.0820[b]	1.0756
II		same as above					.0820	2.7921
III							.0820	14.0910
IV							.0820	35.3376

[a] From Table 24.

[b] From Table 25.

Table 28. Phosphorus enrichment ratios and losses for land management practices by capability classes

Capability class	Management system	Runoff (Ac in.)[a]	Soil loss (tons/ac in.)	Soil loss (tons/ac)[b]	Enrichment ratio[c]	Phosphorus losses[c] (lbs/ton soil)
I	Conv.till.-R_1	5.36	1.0093	5.41	1.76	2.11
	Conv.till.-R_2	3.85	0.5532	2.13	2.24	2.69
	Conv.till.+contour-R_1	4.50	0.7222	3.25	2.01	2.41
	Conv.till.+contour-R_2	3.42	0.3743	1.28	2.60	3.12
	Min.till.-R_1	5.36	0.4683	2.51	2.30	2.76
	Min.till-R_2	3.85	0.2805	1.08	2.84	3.41
	Min.till.+contour-R_1	4.50	0.3356	1.51	2.63	3.16
	Min.till.+contour-R_2	3.42	0.1901	0.65	3.29	3.95
	Perm.past.	1.60	0.0312	0.05	6.65	7.98
II	Conv.till.-R_1		2.6213	14.05	1.27	1.52
	Conv.till.-R_2		1.4364	5.53	1.61	1.93
	Conv.till.+contour-R_1		1.5600	7.02	1.54	1.85
	Conv.till.+contour-R_2		0.8070	2.76	1.99	2.37
	Min.till.-R_1		1.2146	6.51	1.65	1.98
	Min.till.-R_2		0.7247	2.79	2.04	2.45
	Min.till.+contour-R_1		0.7244	3.26	2.01	2.41
	Min.till.+contour-R_2		0.4094	1.40	2.52	3.02
	Conv.till.+terrace-R_1	0.70	0.5571	0.39	2.65	3.18
	Conv.till.+terrace-R_2	0.70	0.2143	0.15	3.69	4.43
	Min.till.+terrace-R_1	0.70	0.2571	0.18	3.46	4.15
	Min.till.+terrace-R_2	0.70	0.1143	0.08	4.59	5.51
	Perm.past.		0.0875	0.14	4.65	5.58

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[a] Runoff values from conv.till.+contour R_1, perm.past., and terracing were obtained from 1970 Report on the Treynor Watersheds, USDA, ARS, SWC., Columbia, Missouri. Conv.till.-R_1 was calculated from Conv. till.+contour-R_1 based on a study reporting 16% reduction in runoff from contour farming (129, p. 276). The reduced runoff factors for conv.till.-R_2 and conv.till.+contour-R_2 were calculated following the example in (86, p. 36). For min.till. activities, the runoff was taken to be the same as for the similar conv.till.activities (86, p. 12).

[b] Taken from Tables 26, 27, 29-32.

[c] The method used in calculating these values is explained in Chapter V, p. 62 and page 63.

Table 28. (Continued)

Capability class	Management system	Runoff (Ac in.)^a	Soil loss (tons/ac in.)	Soil loss (tons/ac)^b	Enrichment ratio^c	Phosphorus losses^c (lbs/ton soil)
III	Conv.till.-R_1		13.2239	70.88	0.72	0.86
	Conv.till.-R_2		7.2442	27.89	0.91	1.09
	Min.till.-R_1		6.1306	32.86	0.94	1.13
	Min.till.-R_2		3.6597	14.09	1.16	1.39
	Conv.till.+terrace-R_1		1.5714	1.10	1.84	2.21
	Conv.till.+terrace-R_2		0.6143	0.43	2.56	3.07
	Min.till.+terrace-R1		0.7286	0.51	2.41	2.89
	Min.till.+terrace-R_2		0.3143	0.22	3.23	3.88
	Perm.past.		0.4312	0.69	2.67	3.20
IV	Conv.till.-R_1		33.1660	177.77	0.52	0.62
	Conv.till.-R_2		18.1662	69.94	0.67	0.80
	Min.till.-R_1		15.3731	82.40	0.68	0.82
	Min.till.-R_2		9.1792	35.34	0.92	1.10
	Conv.till.+terrace-R_1		3.7143	2.60	1.37	1.64
	Conv.till.+terrace-R_2		1.4571	1.02	1.89	2.27
	Min.till.+terrace-R_1		1.7286	1.21	1.78	2.14
	Min.till.+terrace-R_2		0.7429	0.52	2.41	2.89
	Perm.past.		1.6187	2.59	1.68	2.02
VI	Perm.past		3.1312	5.01	1.34	1.61
VII	Perm.past		7.2187	11.55	1.00	1.20

Table 29. Computed erosion rates by land capability for contouring with two crop rotations and two tillage systems

Capability class	Slope length (ft.)	Slope gradient (%)	R	K	LS	P[a]	C	A=RKLSPC (Rotation av; tons/ac)
C-C-S + conventional tillage + contouring								
I	300	1.0	168	.33	.236598	.6	.4125[b]	3.2465
II	300	3.5	168	.33	.614185	.5	.4125	7.0229
C-C-S + minimum tillage + contouring								
I		same as above				.6	.1912[c]	1.5048
II						.5	.1912	3.2552
C-S-C-O-M-M + conventional tillage + contouring								
I		same as above				.6	.1623[d]	1.2773
II						.5	.1623	2.7632
C-S-C-O-M-M + minimum tillage + contouring								
I		same as above				.6	.0820[e]	.6454
II						.5	.0820	1.3961

[a] Source: (128, Table 6, p. 36).

[b] From Table 22.

[c] From Table 23.

[d] From Table 24.

[e] From Table 25.

Table 30. Computed erosion rates by land capability class for C-C-S rotation with terraced land and two tillage systems

Capability class	Slope length (ft.)	Slope gradient (%)	R	K	LS	P[a]	C	A=RKLSPC (Rotation av. tons/ac)
<u>Conventional tillage + terracing</u>								
II	188[b]	4[b]	168	.33	.561615	.03	.4125[c]	.3853
III	138	10	168	.33	1.604687	.03	.4125	1.1009
IV	118	18	168	.33	3.793717	.03	.4125	2.6028
<u>Minimum tillage + terracing</u>								
II						.03	.1912[d]	.1786
III	same as above					.03	.1912	.5103
IV						.03	.1912	1.2064

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[a] Source: (85, Table 13, p. 138).

[b] Source: Technical standards and specifications for conservation practices. Section 4A - Cropland, Work unit technical guide. November 1966.

[c] From Table 22.

[d] From Table 23.

Table 31. Computed erosion rates by land capability class for C-S-C-O-M-M rotation with terraced land and two tillage systems

Capability class	Slope length (ft.)	Slope gradient (%)	R	K	LS	P[a]	C	A=RKLSPC (Rotation av. tons/ac)
<u>Conventional tillage + terracing</u>								
II	188	4	168	.33	.561615	.03	.1623[b]	.1516
III	138	10	168	.33	1.604687	.03	.1623	.4332
IV	118	18	168	.33	3.793717	.03	.1623	1.0241
<u>Minimum tillage + terracing</u>								
II						.03	.0820[c]	.0766
III	same as above					.03	.0820	.2189
IV						.03	.0820	.5174

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[a] Source: (85, Table 13, p. 138).

[b] From Table 24.

[c] From Table 25.

Table 32. Computed erosion rates by land capability class of permanent pasture

Capability class	Slope length (ft.)	Slope gradient (%)	R	K	LS	P	C^a	A=RKLSPC (tons/ac)
I	300	1.0	168	.33	.236598	1	.004	.0525
II	300	3.5	168	.33	.614185	1	.004	.1362
III	600	9.5	168	.33	3.099584	1	.004	.6874
IV	600	17.0	168	.33	7.773211	1	.006	2.5857
VI	600	25.0	168	.33	15.066811	1	.006	5.0118
VII	600	30.0	168	.33	20.835360	1	.010	11.5511

[a] Source: (128, Table 2, lines 120-122, p. 14).

Table 33. Estimates of sediment retention per gully control structure and maximum number of structures required in the basin[a]

Watershed number	Acres in watershed	Sample watersheds		
		Acres per structure	Soil delivered to stream without structures (tons)	Soil delivered to stream with structures (tons)
27	16,920	1,000	22,567	1,849
11	39,294	670	75,673	7,570
23	3,812	480	49,192	4,930
33	9,547	530	143,111	13,118
19	83,100	903	340,905	37,891
15	86,121	840	324,809	57,265
61	7,500	750	53,117	6,051
Totals	246,294	5,173	880,583	128,674

Sediment coefficient: (3.0529 tons/st) (739 ac/st) $(.9247)^b$= -2086 (10^{-3})

Phosphorus coefficient: (3.9529 tons/st) (739 ac/st) (1.2 lbs. P/ton soil) $(.46234)^b$ = -1251.726 (10^{-6}) mg/l

Number of structures

Acres of Class II E - VII E crop and pasture land: 1,161,687[c]

Maximum number of structures permitted: $\frac{1,161,687}{739 \text{ ac/str.}}$ = 1,572 structures

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[a] Source: (85, Table 16, p. 141).

[b] The .9247 and .46235 are conversion factors to obtain sediment and phosphorus coefficients in concentration. These are explained on p. 99 in the text.

[c] From Table 3.

Table 34. Yearly mean discharge, runoff, and suspended sediment loads for Nishnabotna River at Hamburg, Iowa[a]

Water year[b]	Yearly mean discharge (cfs)	Yearly runoff (1000 ac/ft)	Sediment load (1000 tons)	Sediment concentration[c] ppm or mg/l
1940	434	314.7	7,442.9	17,411
41	535	387.3	8,584.6	16,317
42	1282	928.5	13,724.0	10,991
43	850	615.2	12,155.0	14,545
44	1197	869.2	15,464.0	13,095
45	1796	1,300.0	14,604.0	8,270
46	1115	806.9	7,803.0	7,119
47	2572	1,862.0	37,127.0	14,678
48	931	675.5	10,286.0	11,210
49	1090	789.0	9,419.0	8,788
1950	825	597.3	6,595.0	8,128
51	2180	1,526.0	24,262.0	11,704
52	1612	1,170.0	17,500.0	11,011
53	878	635.8	8,120.0	9,402
54	384	278.0	2,830.0	7,494
55	496	359.0	3,920.0	8,038
56	238	172.7	1,570.0	6,692
57	501	362.4	3,970.0	8,046
58	1177	852.4	11,750.0	10,148
59	1231	891.2	12,600.0	10,408
1960	1482	1,076.0	15,950.0	10,912
61	1158	838.6	11,610.0	10,192
62	1819	1,317.0	17,500.0	9,782
63	666	482.2	5,750.0	8,778
Average	1099	796.125	11,689.021	10,544

[a] Source: (85, Table 17, p. 142).

[b] Water year is defined as the period from October 1 to September 30.

[c] Calculated from relationship: concentration = $\frac{736.1501\ Q_c}{Q_w}$ where $\frac{Q_c}{Q_w}$ is tons/ac-ft.

Table 35. Estimated phosphorus constraints for the various suspended sediment levels

Suspended sediment levels (mg/l)	Sediment load[a] (million tons)	Total phosphorus load[b] (tons)	Total phosphorus concentration[c] (mg/l)	Solution phosphorus concentration[c] (mg/l)
10,000	10.81	12,972	11.995	0.600
9,000	9.73	11,676	10.797	0.594
8,000	8.65	10,380	9.598	0.586
7,000	7.57	9,084	8.400	0.580
6,000	6.49	7,788	7.202	0.555
5,000	5.41	6,492	6.003	0.522
4,000	4.33	5,196	4.805	0.476
3,000	3.24	3,888	3.505	0.413
2,000	2.16	2,592	2.397	0.328
1,000	1.08	1,296	1.198	0.209
500	0.54	648	0.599	0.127
250	0.27	324	0.300	0.075
150	0.16	192	0.178	0.049
75	0.08	96	0.089	0.028
37.5	0.04	48	0.044	0.016

[a] Calculated from relationship: concentration = (.9427 X 10^{-3}) (load in tons).

[b] Calculated from the phosphorus loss equation: Np = AS;E, with SP = 1.2, E = 2.0, and divided by 2000 to give the result in tons.

[c] Calculated by taking the total phosphorus concentration times the T/A ratios for various sediment levels from Figure 4.

Table 36. Physical components associated with a 200 acre recreation lake

1. 10 yr. drought evaporation loss:[a]		384 ac-ft.
2. Estimated daily water demand:[b]		2.1 ac-ft./day
Capacity MGD		0.7
Capacity gpm		486
3. Transmission lines:[c]		
Velocity of flow in lines (fps)		3-4
Pipe size (Diameter, inches)		8
Friction loss (H_f), ft/1000 ft.		8.5
4. Wells:		
Number		1
Depth, ft.		50
Pumps:	Capacity, gpm	500
	Number	1
	Type	Vertical
	Lift[d]	Turbine
	Surface water supply	60 ft. + Hf
	Ground water supply	70 ft. + Hf

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[a] Based on 0.10 probability of drought rainfall and evaporation, with rainfall data from Des Moines, Iowa and evaporation information computed from (59).

[b] Daily demand is based on a 6 month operating period.

[c] Source: (21, Figures 5-14, p. 135).

[d] Lift is based on 50 ft. to the reservoir plus 10 ft. to the surface water supply and 20 ft. for the well water supply.

APPENDIX B: COST AND RETURN DATA

Table 37. Annual fixed cost of equipment for C-C-S rotation for conventional tillage

Machine[a]	No.	Size	Cost per machine[b] $	Total cost $	Depreciation, interest, taxes, insurance rate[c] %	Annual fixed cost $
Tractor	2	70 DBHP	9,720	19,440	14.875	2,892
Moldboard plow w/NH_3 applicator[d]	1	5-bot 16"	2,025	2,025	16.875	342
Moldboard plow w/NH_3 applicator	1	5-bot 16"	2,025	2,025	↓	342
Tandem disk w/dry chemical applicator	1	14 ft.	1,777[e]	1,777	↓	300
Conventional row planter	1	6-row 30"	2,457	2,457	↓	415
Rotary hoe	1	6-row 30"	918	918	↓	155
Cultivator (standard)	1	6-row 30"	1,287	1,287	↓	217
Self-propelled combine	1	230 bu/hr	11,934	11,934	↓	2,014
corn head	1	3-row 30"	3,726	3,726	↓	629
platform	1	16 ft.	1,281	1,281	↓	216
Wagons-side dump	3	185 bu.	648	1,944	↓	328
Elevator	1	40 ft.	837	837	↓	141
Fertilizer spreader	1	4 ton bulk	1,620	1,620	↓	273
Stalk chopper	1	12 ft.	1,782	1,782		301
TOTALS				53,053		8,565

[a] Machinery set is based on 450 acres of cropland and days available to perform tillage operations and harvest operations.

[b] Cost data taken from (126, p. 132, 133, 134), except as noted.

[c] Percentages obtained from (26, Table K, p. 15).

[d] Assumed NH_3 tank is supplied by dealer.

[e] Added $35/ft. for dry chemical applicator (26, Table 1).

Table 38. Corn operation times and variable machine costs for conventional tillage for C-C-S rotation on Class I and II lands[a]

Field operation	No. of units	Field time requirements (hr/ac)	Labor requirements (hr/ac)	Fuel, oil, repair,costs ($/ac)
Chop stalks (50%)	1	.085	.100	.210
Disk stalks	1	.142	.160	.260
Spread P and K	1	.230	.270	.214
Plow	2			
5-16" bottoms (corn stalks-50%)		.207	.236	.620
5-16" bottoms(soybeans-50%)		.194	.221	.575
1st disking	1	.180	.200	.350
2nd disking and apply herbicide and insecticide	1	.189[b]	.226[b]	.350
Planting	1	.259	.335	.450
Rotary hoe	1	.110	.113	.200
1st cultivation	1	.200	.220	.420
2nd cultivation	1	.200	.220	.420
Combine	1	.680	.750	1.820[c]
Totals		2.676	3.051	5.889

[a] Data taken from (126, p. 137, 138, 139 and sections 5, 7, 8, 9, p. 108, 109, 111, 112, 113), except as noted.

[b] Adjusted up by .05 and .13 respectively from comparison of 1st and 2nd disking (85, Table 19a, p. 146).

[c] Based on 107 bushels per acre from (32, Table 1, p. 14).

Table 39. Soybean operation times and variable machine costs for conventional tillage for C-C-S rotation on Class I and II lands[a]

Field operations	No. of units	Field time requirements (hr/ac)	Labor requirements (hr/ac)	Fuel, oil, repair costs ($/ac)
Chop stalks	1	.170	.200	.420
Disk stalks	1	.142	.160	.260
Spread P and K	1	.230	.270	.214
Plow 5-16" bottoms (cornstalks)	2	.415	.473	1.240
1st disking	1	.180	.200	.350
2nd disking and apply herbicide, insecticide	1	.189[b]	.226[b]	.350
Planting	1	.250	.333	.450
Rotary hoe	1	.110	.113	.200
1st cultivation	1	.200	.220	.420
2nd cultivation	1	.200	.220	.420
Combine	1	.489	.517	.980
Totals		2.575	2.932	5.304

[a] Data taken from (126, pp. 137, 138, 139 and sections 6, 10, 11, 12, pp. 110, 114, 115, 116), except as noted.

[b] Adjusted up by .05 and .13 respectively from comparison of 1st and 2nd disking (85, Table 19a, p. 146).

Table 40. Annual fixed cost of equipment for C-C-S rotation for minimum tillage system

Machine[a]	No.	Size	Cost per machine[b] ($)	Total cost ($)	Depreciation, interest, taxes, insurance rate[c] (%)	Annual fixed cost ($)
Tractor	1	70 DBHP	9,720	9,720	14.875	1,446
Tractor	1	50 DBHP	6,725	6,725	14.875	1,000
Tandem disk	1	14 ft.	1,187	1,187	16.875	200
Till planter w/fert., herb., insect. attachments	1	6-row 30"	3,100[d]	3,100	↓	523
Cultivator(standard)	1	6-row 30"	1,287	1,287		217
Cultivator(diskhiller)	1	6-row 30"	1,387[e]	1,387		234
Self-propelled combine	1	230 bu/hr	11,934	11,934		2,014
corn head	1	3-row 30"	3,726	3,726		629
platform	1	16 ft.	1,281	1,281		216
Wagons-side dump	3	185 bu.	648	1,944		328
Elevator	1	40 ft.	837	837		141
Fertilizer spreader	1	4 ton bulk	1,620	1,620		273
NH_3 applicator	1	5-knife	1,200[d]	1,200		202
Totals				45,948		7,423

[a] Machine set is based on 450 acres of cropland and day available to perform tillage operations and harvest operations.

[b] Cost data taken from (126, pp. 132, 133, 134), except as noted.

[c] Percentages obtained from (26, Table K, p. 15).

[d] Taken from (26, Table 1).

[e] Adjusted up by .078 after comparison of standard and disk hiller cultivator costs (85, Table 19b, p. 148).

Table 41. Corn and soybean operation times and variable machine costs for minimum tillage for C-C-S rotation on Class I and II lands[a]

Operation	No. of units	Field time requirements hr/ac	Labor requirements hr/ac	Fuel, oil repair costs $/ac
		Corn requirements		
NH_3 application	1	.251	.271	.440
Spread P and K	1	.230	.270	.214
Disk stalks	1	.142	.160	.260
Till plant and fert., herb, insec.	1	.283[b]	.376[b]	.510[c]
1st cultivation	1	.200	.220	.420
2nd cultivation (disk hiller)	1	.200	.220	.420
Combine	1	.680	.750	1.82
Total		1.986	2.267	4.084
		Soybean requirements		
Spread P and K	1	.230	.270	.214
Disk stalks	1	.142	.160	.260
Till plant and fert., herb., insect.	1	.274[b]	.374[b]	.510[c]
1st cultivation	1	.200	.220	.420
2nd cultivation (disk hiller)	1	.200	.220	.420
Combine	1	.489	.517	.980
Total		1.535	1.761	2.804

[a] Data taken from (126, pp. 137, 138, 139 and Sections 5-12, pp. 108-116), except as noted.

[b] Adjusted up by .094 and .123 respectively by comparing requirement of conventional and till planting from (85, Table 190, p. 146).

[c] Adjusted up by .06 as calculated from (26, Table 1) and (45, p. 12).

Table 42. Annual fixed cost of equipment for C-S-C-O-M-M rotation for conventional tillage

Machine[a]	No.	Size	Cost per machine[b] ($)	Total cost $	Deprec., int., taxes, insur. rate[c] %	Annual fixed cost $
Tractor	2	50 DBHP	6,725	13,450	14.875	2,001
Moldbord plow w/NH_3 applicator[d]	1	4 bot. 16"	1,793	1,793	16.875	303
Moldboard plow w/NH_3 applicator	1	3 bot. 16"	1,609	1,609	↓	272
Tandem disk w/dry chemical appl.	1	12 ft.	1,370[e]	1,370		231
Conv. row planter	1	4 row 38"	1,625	1,625		274
Rotary hoe	1	4 row 38"	626	626		106
Cultivator(standard)	1	4 row 38"	1,000[f]	1,000		169
Self-prop.combine	1	185 bu/hr	9,612	9,612		1,622
corn header	1	2 row 40"	2,322	2,322		392
platform	1	14 ft.	1,170[g]	1,055		178
Wagon-side dump	3	150 bu.	500	1,500		253
Drill w/fert. and grass attachm't	1	12 ft.	1,304[h]	1,304		220
Mower	1	7 ft.	870[i]	870		147
Conditioner	1	7 ft.	900[i]	900		152*
Rake	1	7 ft.	700[i]	700		118*
Baler (P.T.O.)	1	6 ton/hr	2,200[i]	2,200		371*
Elevator	1	40 ft.	837	837		141
Fertilizer spreader	1	4 ton bulk	1,620	1,620		273
Stalk chopper	1	6 ft.	902	902		152
Totals				45,295		7,375

[a] Machinery set is based on 450 acres of cropland and days available to perform tillage and harvest operations.

[b] Cost data taken from 126, pp. 132, 133, 134), except as noted.

[c] Percentages obtained from (26, Table K, p. 15).

[d] Assumed NH_3 tank supplied by dealer.

[e] Added 35/ft. dry chemical applicator (26, Table 1).

[f] Taken from (26, Table 1).

[g] Estimated from (126, p. 133 and 134).

[h] Adjusted up 20% from 1967 price in (53, Table 4.1, p. 113).

[i] Obtained from (2, Table 2 and Table 4).

Table 43. Corn operation times and variable machine costs for conventional tillage for C-S-C-O-M-M rotation on Class I and II lands[a]

Operation	No. of units	Field time requirements (hr/ac)	Labor requirements (hr/ac)	Fuel, oil, repair costs ($/ac)
Disk stalks (50%)	1	.083[b]	.096[b]	.135[b]
Spread P and K	1	.230	.270	.214
Plow	2			
4-16" bottoms (soybeans 50%)		.230	.260	.595
3-16" bottoms (meadow 50%)		.284	.324	.685
1st disking	1	.216[c]	.240[c]	.363[c]
2nd disking+herb., insect.	1	.227[d]	.271[d]	.363[c]
Planting	1	.253	.327	.430
Rotary hoe	1	.130	.133	.210
1st cultivation	1	.190	.210	.420
2nd cultivation	1	.190	.210	.420
Combine	1	.720	.794	1.710
Totals		2.753	3.135	5.545

[a] Data taken from (126, pp. 137, 138, 139 and sections 5, 7, 8, 9, pp. 108-109, 111, 112, 113), except as noted.

[b] Estimated from (126, p. 137).

[c] Estimated from (126, p. 137).

[d] Adjusted up by .05 and .13 respectively from comparison of 1st and 2nd disking (85, Table 19a, p. 146).

Table 44. Soybean operation times and variable machine costs for conventional tillage for C-S-C-O-M-M rotation on Class I and II lands[a]

Operation	No. of units	Field time requirements (hr/ac)	Labor requirements (hr/ac)	Fuel, oil, repair costs ($/ac)
Chop stalks	1	.300	.330	.340
Disking stalks	1	.167[b]	.192[b]	.270[b]
Spread P and K	1	.230	.270	.214
Plow (4-16" bottoms)	1	.490	.560	1.29
1st disking	1	.216[c]	.240[c]	.363[c]
2nd disking+herb., insect.	1	.227[d]	.271[d]	.363[c]
Planting	1	.244	.325	.430
Rotary hoe	1	.130	.133	.210
1st cultivation	1	.190	.210	.420
2nd cultivation	1	.190	.210	.420
Combine	1	.530	.560	1.000
Totals		2.914	3.301	5.320

[a] Data taken from (126, pp. 137, 138, 139 and Sections 6, 10, 11, 12, pp. 110, 114, 115, 116) except as noted.

[b] Estimated from (126, p. 137).

[c] Estimated from (126, p. 137).

[d] Adjusted up by .05 and .13 respectively from comparison of 1st and 2nd disking (85, Table 19, p. 146).

Table 45. Annual fixed cost of equipment for C-S-C-O-M-M rotation for minimum tillage

Machine[a]	No.	Size	Cost per machine[b] ($)	Total cost ($)	Deprec., interest, taxes, insurance rate[c]	Annual fixed cost ($)
Tractor	1	50 DBHP	6,725	6,725	14.875	1,000
Tractor	1	30 DBHP	4,000[d]	4,000	14.875	595
Tandem disc	1	12 ft.	950	950	16.875	160
Till planter w/fert., herb.,and insect. attachment	1	4-row 38"	2,068[e]	2,068	↓	349
Cultivator(standard)	1	4-row 38"	1,000[f]	1,000		169
Cultivator(disk hiller)	1	4-row 38"	1,095[g]	1,095		185
Self-propelled combine	1	185 bu/hr	9,612	9,612		1,622
corn header	1	2-row 40"	2,322	2,322		392
platform	1	14 ft.	1,170[h]	1,170		178
Wagon-side dump	1	150 bu.	500	1,500		253
Drill w/fert. and grass attachment	1	12 ft.	1,304[i]	1,304		220
Mower	1	7 ft.	870[j]	870		147
Rake	1	7 ft.	700[j]	700		118
Baler - P.T.O.	1	6 ton/hr	2,200[j]	2,200		371
Elevator	1	40 ft.	837	837		141
Fertilizer spreader	1	4 ton bulk	1,620	1,620		273
NH$_3$ applicator	1	5 knife	1,200[f]	1,200		202
Conditioner	1	7 ft.	900[j]	900		152
Totals				39,958		6,527

[a] Machinery set is based on 450 acres of cropland and the time available to perform tillage and harvest operations.

[b] Cost data taken from (126, pp. 132, 133, 134), except as noted.

[c] Percentages obtained from (26, Table K, p. 15).

[d] Cost taken from (26, Table 3).

[e] Estimated $137 per row additional cost for till planter over conventional planter from six-row units (26, Table 1).

[f] Taken from (26, Table 1).

[g] Assumed the same as for six-row disk hiller.

[h] Estimated from (126, pp. 132, 133).

[i] Adjusted 1967 price by 20% (53, Table 4.1, p. 113).

[j] Taken from (2, Tables 2 and 4).

Table 46. Corn and soybean operation times and variable machine costs for minimum tillage for C-S-C-O-M-M rotation on Class I and II lands[a]

Operation	No. of units	Field time requirements (hr/ac)	Labor requirements (hr/ac)	Fuel, oil, repair costs ($/ac)
			Corn	
NH_3 application	1	.251	.271	.440
Spread P and K	1	.230	.270	.214
Disk	1	.167[b]	.192[b]	.270[b]
Till plant + fert., herb., insect.	1	.277[c]	.367[c]	.490[d]
1st cultivation(50%)	1	.095	.105	.210
2nd cultivation (disk hiller-50%)	1	.095	.105	.210
Combine	1	.720	.794	1.710
Totals		1.835	2.104	3.544
			Soybeans	
Spread P and K	1	.230	.270	.214
Disk stalks	1	.167[b]	.192[b]	.270[b]
Till plant + fert., herb., insect.	1	.267[c]	.365[c]	.490[d]
1st cultivation	1	.190	.210	.420
2nd cultivation	1	.190	.210	.420
Combine	1	.530	.560	1.000
Totals		1.574	1.807	2.814

[a] Data taken from (126, p. 137, 138, 139 and Section 5-12, p. 108-116), except as noted.

[b] Estimated from (126, p. 137).

[c] Adjusted up by .094 and .123 respectively by comparison of requirements for conventional and till planting from (85, Table 19a, p. 146).

[d] Adjusted by 6c as calculated from (26, Table 1) and (45, p. 12).

Table 47. Oats and hay operation times and variable machine costs for conventional and minimum tillage for C-S-C-O-M-M rotation on Class I and II lands[a]

Operation	No. of units	Field time requirements (hr/ac)	Labor requirements (hr/ac)	Fuel, oil, repair costs ($/ac)
			Oats	
Spread fertilizer	1	.210	.240	.214
Disk stalks	1	.167[b]	.192[b]	.217[b]
Seeding	1	.150	.180	.150
Combine.	1	--	.440	1.000
Totals		.527	1.052	1.634
			Hay	
Pasture clip		--	.190	.190
Spread fertilizer		.220	.240	.214
Clip stubble (50%)		--	.190	.190
Mow (3 times/yr)		.990	1.190	1.200
Condition (3 tm/yr)			1.080	1.100
Rake (3 tm/yr)		.870	1.050	1.100
Bale (4 ton/ac)		.790	1.070	3.260
Totals		3.770	4.820	7.064
		Pasture	.620	.594

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[a] Data taken from (12, p. 137, 138, 139 and Sections 13-16, p. 117-121), except as noted.

[b] Estimated from (126, p. 137).

Table 48. Variable and fixed costs for C-C-S rotation for two tillage systems[a]

Tillage system	Direct labor (hr/ac)	Labor costs at \$2/hr. (\$/ac)	Fuel,oil, repairs (\$/ac)	Total variable costs (\$/ac)	Fixed costs (\$/ac)	Total cost (\$/ac)
<u>Conventional tillage</u>						
Flatland and parallel terraces	3.011[b]	6.02	5.69[b]	11.71	19.03[c]	30.74
Upland and contour[d]	3.975	7.95	7.51	15.46	19.03	34.49
<u>Minimum tillage</u>						
Flatland and parallel terraces	2.098[e]	4.20	3.66[e]	7.86	16.50[f]	24.36
Upland and contour[d]	2.769	5.54	4.83	10.37	16.50	26.87

[a] These costs include only time related factors: plow, plant, cultivate, harvest. Costs of fertilizer, seeds, herbicides, insecticides, and storage are excluded.

[b] Weighted average obtained from Table 38 and Table 39.

[c] Computed from Table 37 by dividing total fixed costs by 450 acres.

[d] Calculated by taking flatland values times 1.32, taken from Seay (85, p. 68).

[e] Weighted average obtained from Table 41.

[f] Computed from Table 40 by dividing total fixed cost by 450 acres.

Table 49. Variable and fixed costs for C-S-C-O-M-M for two tillage systems[a]

Tillage system	Direct labor (hr/ac)	Labor costs at $2/hr. ($/ac)	Fuel,oil, repairs ($/ac)	Total variable costs ($/ac)	Fixed costs ($/ac)	Total cost ($/ac)
Conventional tillage						
Flatland and parallel terraces	3.377[b]	6.75	5.36[b]	12.11	16.39[c]	28.50
Upland and contour[d]	4.458	8.92	7.08	16.00	16.39	32.39
Minimum tillage						
Flatland and parallel terraces	2.784[e]	5.57	4.28[e]	9.85	14.50[f]	24.35
Upland and contour[d]	3.675	7.35	5.65	13.00	14.50	27.50

[a] These costs include only time related factors: plow, plant, cultivate, harvest. Costs of fertilizer, seeds, herbicides, insecticides and storage are excluded.

[b] Weighted average obtained from Tables 43, 44, and 47.

[c] Computed from Table 42 by dividing total fixed costs by 450 acres.

[d] Calculated by taking flatland values times 1.32, taken from Seay (85, p. 68).

[e] Weighted average obtained from Tables 46 and 47.

[f] Computed from Table 45 by dividing total fixed costs by 450 acres.

Table 50. Fertilizer levels and costs for two crop rotations

Crop[a]	N	P_2O_5[b]	K_2O[c]
Continuous corn	120	60	10
Corn after soybeans	100[d]	60	10
Corn after meadow (20-50% legume)	20[d]	60	10
Soybeans	0	50	0
Oats	40	60	10
Legume-grass meadow	0	40	10
Average level and cost for C-C-S			
C-C-S (Av. lbs/ac)	73.3	56.6	6.6
C-C-S (Av. $/ac)[e]	3.08		
Average level and cost for C-S-C-O-M-M			
C-S-C-O-M-M (Av.lbs/ac)	26.6	51.7	8.3
C-S-C-O-M-M (Av. $/ac)	1.12	4.14	.33

[a] Fertilizer levels are estimated from (117, p. 12; 116, pp. 5,6,7, and 12; 119, Table 8A, p. 40; 118, Table 1, p. 3).

[b] To obtain lbs. P take P_2O_5 x .44.

[c] To obtain lbs. K take K_2O x .83.

[d] Fertilizer levels are adjusted following soybeans or meadow as suggested by (118, Table 21, p. 3).

[e] Costs are based on N at 4.2¢, P_2O_5 at 8¢, K_2O at 4¢ per pound taken from (43, p. 2), and 9¢/lb. for granular nitrogen.

Table 51. **Fertilizer, seed, herbicide and insecticide, and hauling and storage costs for two rotations**

Crop	Fertilizer[a]	Seed[b]	Herb.+insect.[b] ($/ac)	Hauling + storage[c]	Total
			C-C-S rotation		
Corn	10.15	5.00	4.50	3.69	
Soybeans	4.00	4.00	3.00	1.41	
Rotation average[d] (C-C-S)	8.10	4.67	4.00	2.93	19.70
			C-S-C-O-M-M rotation		
Corn	7.62	5.00	4.50	3.69	
Soybeans	4.00	4.00	3.00	1.41	
Oats	8.80	2.00	.50	1.74	
Meadow	3.60	3.50	--	1.25	
Rotation average[d] (C-S-C-O-M-M) Min.till.	5.87	3.25	2.08[e]	2.17	13.37

[a] Fertilizer costs per acre of crop are calculated from data presented in Table 50.

[b] Seed and chemical costs are taken from (44, Table 2, p. 3).

[c] Hauling and storage costs are based on weighted average yields, weighted by crop acres in the capability classes and are 97, 37, and 47 bu/ac for corn, soybeans and oats, respectively. Costs of 3.8¢/bu. for corn and soybeans, 3.7¢/bu. for oats, and $1.25/ac for hay were obtained from (43, pp. 2-5; 126, p. 108, 110, 117, and 119).

[d] Rotation average is simply a weighted average by crops in the rotation.

[e] Added on an additional $2.21/ac for cost of killing meadow with paraquat under minimum tillage. This is based on a quart of paraquat/ac or $7.00/ac and ortho X-77 at 25¢/ac, obtained from W. A. Myes, Chevron Chemical Company, Ortho Division, Des Moines, Iowa. Also includes $1/ac for spraying charges.

Table 52. Annual renovation and maintenance costs for permanent pasture[a,b]

Operations	Seed rate (lb/ac)	Hours/ac	$/ac
Renovation			
Equipment costs (plow, disk, harrow, drill, cultivate, clip)		1.71	6.95
Labor ($2/hr.)		1.71	3.42
Seed			
Smooth bromegrass	15		4.05
Oats			2.50
Fertilizer[c]			
N (9/lb)	30		2.70
P_2O_5 (8¢/lb)	40		3.20
Lime			12.00
Total renovation costs			34.82
Annual renovation costs (10 years use)			3.48
Interest (opportunity cost) at 7.5%			1.31
Total annual renovation cost			4.79
Maintenance			
Clip (labor and machinery)			1.68
Fertilizer[d]			
N (9¢/lb)	100		9.00
P_2O_5 (8¢/lb)	40		3.20
Total annual maintenance cost			13.88
Total annual renovation and maintenance cost			18.67

[a] Taken from (85, Table 21, p. 150), except as noted.

[b] Pasture of smooth bromegrass with continuous grazing.

[c] Fertilizer prices taken from (43, p. 21 and 24).

[d] Fertilizer levels obtained from (116, p. 9).

Table 53. Crop productivities, gross revenues, and land values by capability classes for Marshall silty clay loam[a]

Capa-bility class	Slope phase[d]	Erosion phase[d]	Yield[b]				Prop prices--1967-70[c]			
			Corn bu/ac	Soybeans bu/ac	Oats bu/ac	Hay tons/ac	Corn $/bu	Soybeans $/bu	Oats $/bu	Hay $/ton
I	A	0	109	41	54	4.1	1.10	2.51	0.64	20.00
II	B	1	104	40	52	4.0				
III	C	2	99	38	49	3.8				
	D	3	84	32	42	3.2				
	Aug.[e]									
IV	E	3	69	26	34	2.6				
VI	F	3	-	-		2.0[b]				
VII	G	3	-	-		1.8[c]				

[a] This table follows that presented in (85, Table 22, pp. 151-152).

[b] Corn yields and hay yields for classes VI and VII were taken from footnote a, _supra_. Other yields are computed by multiplying corn yield by .38, .50, and .038 for soybeans, oats, and hay, respectively, as suggested by (32, p. 7).

[c] Average of 1967-70 price as reported by (78).

[d] Slope and erosion phases are presented in (32, p. 12).

[e] Capability class III is assumed to be half in slope phase C and half in slope phase D.

Table 53. (Continued)

					Gross revenue						
Capability class	Corn $/ac	Soybeans $/ac	Oats $/ac	Hay $/ac	C-C-S rotation average $/ac	C-S-C-O-M-M rotation average $/ac	Perm. past.[g]	CRS[f]	Ratio: CRS CRS=95[f]	Land value[h] $/ac	Charge to land at 8.0%[i] $/ac
I	119.90	102.91	34.56	82.00	114.24	90.21	57.40	90	.9474	453.80	36.30
II	114.40	100.41	33.28	80.00	109.74	87.08	56.00	83	.8737	418.50	33.48
III	108.90	95.38	31.36	76.00	104.39	82.76		68	.7158	342.87	27.43
	92.40	80.32	26.88	64.00	88.37	70.00		55	.5789	277.29	22.18
				70.00	96.38	76.38	49.00				24.80
IV	75.90	65.26	21.76	52.00	72.35	57.14	39.00	45	.4737	226.90	18.15
VI	-	-	-	40.00	-	-	30.00	25	.2632	126.07	10.09
VII	-	-	-	36.00	-	-	27.00	15	.1579	75.63	6.05

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[f] CRS="corn suitability rating," and is taken from footnote a, *supra*, then a ratio is computed with CRS=95 the maximum value in Marshall soil association.

[g] Gross return from perm. past. is estimated at 65, 70, and 75% utilization of hay valued at the market price of hay, for land classes I and II, III and IV, and VI and VII, respectively.

[h] $479 per acre for "high grade land" in southwest Iowa as reported by (78). The CRS ratio X 479 = land value.

[i] Interest rate based on that reported by Agricultural Finance Branch, Farm Production Economic Division, ERS, USDA for first 6 months of 1971.

Table 54. Cost of level terraces with grassed backslopes by land capability class for two rotations[a]

Capability class	Terrace interval[b] (ft.)	Terrace footage[c] (ft/ac)	Unit cost ($/ac)	Construction cost ($/ac)	Annual capital chrg. at 8% ($/ac)	Annual maintenance cost ($/ac)
II	188	231.7	0.26	60.24	4.81	0.06
III	138	315.7	0.26	82.08	6.57	0.06
IV	118	369.2	0.26	95.99	7.68	0.06

	Gross revenue[d]		Production costs[e]				Net revenue forgone/ac			
	R_1 ($/ac)	R_2 ($/ac)	CR_1 ($/ac)	MR_1 ($/ac)	CR_2 ($/ac)	MR_2 ($/ac)	CR_1 ($/ac)	MR_1 ($/ac)	CR_2 ($/ac)	MR_2 ($/ac)
II	109.74	87.08	50.44	44.06	41.87	38.93	59.30	65.68	45.21	48.15
III	96.38	76.38	54.19	46.57	45.76	42.08	42.19	49.81	30.62	34.30
IV	72.35	57.14	65.19	46.57	45.76	42.08	18.16	25.78	11.38	15.06

	% land in backslope[b]	$/ac of terraced land				Total cost(cap.,maint.,prod. forgone)			
		CR_1 ($/ac)	MR_1 ($/ac)	CR_2 ($/ac)	MR_2 ($/ac)	CR_1 ($/ac)	MR_1 ($/ac)	CR_2 ($/ac)	CR_2 ($/ac)
II	4.26	2.53	2.80	1.93	2.05	7.40	7.67	6.80	6.92
III	13.0	5.48	6.48	3.98	4.46	12.11	13.11	10.61	11.09
IV	23.7	4.30	6.11	2.70	3.57	12.04	13.85	10.44	11.31

[a] Data on terrace construction cost is taken from (85, Table 23, pp. 153-154).

[b] Terrace intervals and percent of land in backslope were obtained from (94).

[c] Feet of terrace per acre = 43,560 ft/ac divided by terrace interval.

[d] Taken from Table 53.

[e] Taken from Tables 48, 49, and 51.

Table 55. Procedure used to derive construction costs associated with improved water quality

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1. Construction cost equations[a]
   a. Medium quality water (400 JTU = 600 mg/l suspended sediment)

$$\begin{aligned} C_1 &= .52Q^{.57} && \text{where: } C = \text{construction cost} \\ &= .52\ (25^{.57}) && \phantom{\text{where: }} Q = \text{MGD treated} \\ &= \$876,668 \end{aligned}$$

   b. Low quality water (12000 JTU = 18000 mg/l suspended sediment)

$$\begin{aligned} C_2 &= .62\ Q^{.57} \\ &= .62\ (2.5^{.57}) \\ &= \$1,045,258 \end{aligned}$$

2. Change in construction cost per mg/l change in suspended sediment.

$$C_A = \frac{C_2 - C_1}{S_2 - S_1}$$

where: C_A = average construction cost per mg/l change in suspended sediment
S_1 = 600 mg/l suspended sediment
S_2 = 18000 mg/l " "

$$C_A = \frac{1,045,258 - 876,668}{18,000 - 600}$$

$$C_A = \$9.69 \text{ per mg/l}$$

3. Capital recovery cost[b]

$$R = \frac{Ai\ (1 + i)^n}{(1+i)^{n-1}}$$

where R = annual cost
A = construction cost
i = interest rate
n = design period

   a. Interest rates used are 4% and 8%[c]
   b. Design period is 40 years[d]

$$R_1 = \frac{A\ (0.04)(1.04)^{40}}{(1.04)^{39}} = \frac{A\ (0.04)\ (4.80102)}{(4.61637)} = A\ (0.0416)$$

$$R_2 = \frac{A\ (0.08)(1.08)^{40}}{(1.08)^{39}} = \frac{A(0.08)(21.72452)}{(20.11530)} = A(0.0864)$$

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[a] Source: (122, Figures 5-9, p. 91).

[b] Source: (85, Table 24, p. 155).

[c] Interest rate of 4% is that used by Frankel (35, Table XI, p. 48) and 8% is that used in this study for agricultural land.

[d] Source: (35, Table XI, p. 48).

Table 56. Construction costs associated with incremental changes in suspended sediment levels

Suspended sediment level (mg/l)	Total construction cost[a] ($)	Annual construction cost[b] ($)		Incremental construction cost[c] ($/mg/l)	
		4%	8%	4%	8%
10,000	967,738	40,258	83,612	0.403	0.837
9,000	958,048	39,855	82,775	↓	↓
8,000	948,358	39,452	81,938		
7,000	938,668	39,049	81,101		
6,000	928,978	38,645	80,264		
5,000	919,288	38,242	79,426		
4,000	909,598	37,839	78,589		
3,000	899,908	37,436	77,752		
2,000	890,218	37,033	76,915		
1,000	880,528	36,630	76,078		
500	875,683	36,428	75,659		
250	873,260	36,328	75,450		
150	872,291	36,284	75,366		
75	871,564	36,257	75,303		
37.5	871,201	36,242	75,272		

[a] Computed with the construction cost equation (C_2) and the change in construction cost equation (C_A) developed in Table 55.

[b] Calculated by using the capital recovery equations from Table 55.

[c] Derived by taking difference in annual construction cost among two sediment levels and dividing by mg/l change in the sediment level. Because of rounding all of these values were not exactly .403 and .837.

Table 57. Chemical costs associated with incremental change in suspended sediment level

Suspended sediment level (mg/l)	Turbidity level[a] (JTU)	Aluminum sulfate[b] (lbs/day)	Total annual aluminum costs[c] ($)	Incremental aluminum costs[d] ($/mg/l)
10,000	6667	2,415	25,651	-
9,000	6000	2,185	23,208	2.44
8,000	5333	1,955	20,765	↓
7,000	4667	1,725	18,322	
6,000	4000	1,495	15,879	
5,000	3333	1,265	13,436	
4,000	2667	1,035	10,993	
3,000	2000	805	8,550	
2,000	1333	575	6,107	
1,000	667	345	3,664	
500	333	230	2,443	
250	167	173	1,838	
150	100	150	1,593	
75	50	133	1,413	
37.5	25	123	1,306	

[a] Suspended sediment is converted to JTU by ratio: 1JTU = 1.5 mg/l SS.

[b] Quantity of aluminum sulfate for a 2.5 MGD plant is computed from equation: Al = 46 + .138 JTU; where Al is the lbs. of aluminum per mgd treated.

[c] Annual aluminum cost is based on aluminum sulfate at 58.20/ton (28).

[d] Derived by taking difference among two sediment levels and dividing by mg/l change in suspended sediment.

Table 58. Construction costs associated with a 200 acre recreation lake

	Line diameter (in)	Miles of line	$1000/mi[b]	Total cost ($)	Annual cost[a] n=30, i=.04 ($/yr)
1. Transmission costs					
	8	1	36,750	36,750	1,529
	8	1.5	36,750	55,125	2,293
2. Pumpage cost[c]					
	8	1			654
	8	1.5			723
3. Well cost[d]					Annual cost[a] n=25, i=.04 ($/yr)
					146
4. Pump cost[d]					Annual cost[a] n=15, i=.04 ($/yr)
Surface water					149
Ground water					140
5. Lake construction cost[e]					Annual cost[a] n=100, i=.04 ($/yr)
Total cost = 235,000					9,776
6. Treatment cost (fixed and variable)				$/1000gal[f]	$/yr for 0.7 mgd
Surface supply				0.083	10,541
7. Total annual cost					
Surface supply					23,482
Ground water supply					12,245

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[a] Annual capital recovery cost computed with formula taken from (85, Table 24, p. 155).

[b] Cost computed using the relationship in (46) and costs adjustment from 1964 to 1970 level using (29, 31).

[c] Calculated using the technical information from Table 36, the relationships developed in (47) and a power cost of $.01/kwh.

[d] Computed using the technical information in Table 36, relationships given in (48) and adjusting costs from the 1966 to 1970 level from (30, 31).

[e] Source: (25, Figure 1, pp. 9-645).

[f] Source: (85, Table 25, p. 156).