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ABSTRACT

This volume resulted from the formal papers and comments presented at an invitational symposium by recognized water experts representing a variety of disciplines and societal interests. The focus of the symposium was on the definition and interpretation of water quality integrity as viewed by representatives of state governments, industry, academia, conservation and environmental groups, and others of the general public. This volume is organized in six parts: (1) an overview, (2) chemical integrity, (3) physical integrity, (4) biological integrity--a qualitative appraisal, (5) biological integrity--a quantitative determination, and (6) integrity--an interpretation. (BB)

THE INTEGRITY OF WATER

Proceedings of a Symposium

March 10-12, 1975

Washington, D.C.

U.S. Environmental Protection Agency
Office of Water and
Hazardous Materials

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THE INTEGRITY OF WATER

a symposium

SYMPOSIUM COORDINATORS:
R. Kent Ballentine and Leonard J. Guarraia
Water Quality Criteria Staff, EPA
Washington, D.C.

OPENING SESSION

Chairman: Kenneth M. Mackenthun, Acting Director, Technical Standards Division, Office of Water and Hazardous Materials, EPA, Washington, D.C.

Speakers: Kenneth M. Mackenthun
- James L. Agee, Assistant Administrator, Office of Water and Hazardous Materials, EPA, Washington, D.C.
- Thomas Jorling, Director, Center for Environmental Studies, Williamstown, Massachusetts
- Donald Squires, Director, State University of New York Sea Grant Program, Albany, New York

CHEMICAL INTEGRITY

Chairman: Dwight G. Ballinger, National Environmental Research Center, EPA, Cincinnati, Ohio

Speakers: Bostwick Ketchum, Director, Woods Hole Oceanographic Institute, Woods Hole, Massachusetts
- Arnold Greenberg, Chief, Chemical and Radiological Laboratories, State of California Department of Public Health, Berkeley, California
- Jay Lehr, Executive Secretary, National Water Well Association, Columbus, Ohio

PHYSICAL INTEGRITY

Chairman: Richard K. Ballentine, Water Quality Criteria Staff, EPA, Washington, D.C.

Speakers: Donald J. O'Connor, Professor of Environmental Engineering, Manhattan College, New York, New York
- Donald R. F. Harleman, Professor of Civil Engineering and Director, Parson's Laboratory for Water Resources, Massachusetts Institute of Technology, Cambridge, Massachusetts
- John M. Wilkinson, A. D. Little, Inc., Cambridge, Massachusetts

BIOLOGICAL INTEGRITY— A QUALITATIVE APPRAISAL

Chairman: Leonard J. Guarraia, Water Quality Criteria Staff, EPA, Washington, D.C.

Speakers: David G. Frey, Indiana University, Bloomington, Indiana
- George Woodwell, Brookhaven National Laboratories, Upton, Long Island, New York
- Charles Coutant, Oak Ridge National Laboratory, Oak Ridge, Tennessee
- Ruth Patrick, Chief, Curator of Limnology, Academy of Natural Sciences, Philadelphia, Pennsylvania

BIOLOGICAL INTEGRITY— A QUANTITATIVE DETERMINATION

Chairman: David G. Frey, Indiana University, Bloomington, Indiana

Speakers: Ray Johnson, National Science Foundation, Washington, D.C.
- John Cairns, Virginia Polytechnic Institute and State University, Blacksburg, Virginia
- Gerald T. Orlob, Resource Management Associates, Lafayette, California
- J. P. H. Batteke, Chief, Social Sciences Division, Environment Canada, Burlington, Ontario

INTEGRITY—AN INTERPRETATION

Chairman: Martha Sager, Effluent Standards and Water Quality Information Advisory Committee, EPA, Washington, D.C.
- Ronald B. Robie, Director, Department of Water Resources, The Resources Agency, Sacramento, California
- Ronald B. Outen, National Resources Defense Council, Washington, D.C.
- R. M. Billings, Director of Environmental Control, Kimberly-Clark, Neenah, Wisconsin
- Gladwin Hill, National Environmental Correspondent, New York Times, New York

Following each presentation, Symposium participants were encouraged to question the speaker. These discussions were recorded by a professional reporting service and appear at the conclusion of each paper. They have been minimally edited, simply for clarification of the spoken word in print.

FOREWORD

"The Integrity of Water" results from the formal papers and comments presented at an invitational symposium by recognized water experts representing a variety of disciplines and societal interests. The focus of the symposium was on the definition and interpretation of water quality integrity as viewed and discussed by representatives of State governments, industry, academia, conservation and environmental groups, and others of the general public. The symposium was structured to address quantitative and qualitative characteristics of the physical, chemical, and biological properties of surface and ground waters.

It is recognized that streams, lakes, estuaries, and coastal marine waters vary in size and configuration, geologic features, and flow characteristics, and are influenced by climate and meteorological events, and the type and extent of human impact. The natural integrity of such waters may be determined partially by consulting historical records of water quality and species composition where available, by conducting ecological investigations of the area or of a comparable ecosystem, and through modeling studies that provide an estimation of the natural ecosystem based upon information available. Appropriate water quality criteria present quality goals that will provide for the protection of aquatic and associated wildlife, man and other users of water, and consumers of the aquatic life.

This volume adds another dimension to our recorded knowledge on water quality. It brings into sharp focus one of the basic issues associated with the protection and management of this Nation's valued aquatic resource. It highlights, once again, our unqualified dependence upon controlling water pollution if we are to continue to have a viable and complex society. The Congress has provided us with strong and comprehensive water pollution control laws. In accordance with the advances in research and development and with our increased knowledge about the environment, these laws will receive further congressional consideration and modification as appropriate. It is through the efforts of those who participated in making this volume possible that attention is focused once again on the basic goals of water quality to support the dynamic needs of this generation and of others to come.

Douglas M. Costle, Administrator
U.S. Environmental Protection Agency
June, 1977

CONTENTS

OVERVIEW

CHEMICAL INTEGRITY

PHYSICAL INTEGRITY

BIOLOGICAL INTEGRITY—A QUALITATIVE APPRAISAL

BIOLOGICAL INTEGRITY—A QUANTITATIVE DETERMINATION

INTEGRITY—AN INTERPRETATION

OVERVIEW

THE PROBLEM

JAMES L. AGEE
Assistant Administrator for
Water and Hazardous Materials
Environmental Protection Agency

The major thrust of this symposium is to more clearly define and delimit "The Integrity of Water." An individual's perception of aquatic integrity will vary as I am sure we shall see in the discussions that follow. The enhancement of water quality, as a vital resource, is a challenge that must be met by our modern society. We have an innate obligation to those who follow in our footsteps to deliver to them a water resource that can meet the use demands of their generation. Positive action to assure attainment of this goal was initiated with the passage of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500).

P.L. 92-500 is one of the most comprehensive and complex environmental laws which has ever been enacted. All facets of the Act bear upon the basic goal to restore and maintain the chemical, physical, and biological integrity of the Nation's waters.

The Act provides for an active research and development program which addresses a variety of issues defining the aquatic environment. Key areas focus on human health effects of water pollution, fate and effects of pollutants on the environment, and advanced waste treatment technology, to name but a few. Both the monitoring of water quality and the development of those tools essential to the monitoring effort are essential to support the overall goal of defining the integrity of water.

Technical assistance to State and local governments is an integral part of the overall program to bring about achievement of the 1977 and 1983 goals. This assistance takes many forms. There is an active intergovernmental exchange program where Federal personnel are loaned to a local or State government to establish programs or to help in the ongoing pollution control program. Cooperation in data management and retrieval, sharing of technical information, regional/State planning efforts, all help to establish a better mode of communication.

Under Section 307(a), toxic pollutant effluent standards, the Agency has proposed a list of toxic pollutants. However, it should be recognized that other sections of the Act, and for that matter, other legislation (Federal Insecticide, Fungicide, and Rodenticide Act) also can be effectively used to control pollutants that may be toxic in certain amounts. The toxic pollutant effluent standards are directed against continuous discharges. Accidental spills of hazardous pollutants are also of major concern. To evolve a coherent toxic and hazardous materials control program on a continuing basis provides a substantial challenge to the Agency.

The Environmental Protection Agency continues to emphasize construction grants as a high priority item. Municipal projects form a central core to many achievements of both the effluent and the water quality requirements of 1977 and 1983. In the past 28 months over $3.5 billion of the $9 billion made available for construction of municipal treatment plants were obligated. About $6.5 billion will be obligated by July 1975. Coordinated efforts by EPA, States, and communities remain essential to comply with the conditions for grant awards, as well as to see that applications are quickly processed and awarded.

Permit compliance assurance activities are to increase in this fiscal year as an outgrowth of priorities of the previous years. Emphasis on permit issuance is to be replaced by the initiation and conduct of a compliance assurance program which will be based upon issued permits specifying levels of control and phased dates for achievement.

There has been a change in the Agency's emphasis for achieving better water quality. The shift has been away from a sole reliance upon water quality standards to a combination of best technology and water quality standards. The shift in direction has been dictated by passage of the Act. Under former law the water quality standards were the main mechanisms by which water quality was to be achieved. Under the present Act both best technology and water quality standards are to be used to achieve the goals. Basically, this has been a shift away from dependence upon the assimilation capacity of water to one of best practicable treatment as a means to manage effluent concentration.

This transition has taken a great deal of effort and time. Development of effluent limits for industrial categories and the National Pollution Discharge Elimination System permits have necessitated a major commitment of personnel. The total effort in the first 2 years of implementation proceeded in less than optimal fashion. Some steps lagged; others were poorly synchronized with other dependent areas. Many of the problems resulted from having to quickly carry out the requirements of the Act in the time frame specified by the law.

These situations should not be repeated in the second phase. Effluent guidelines, water quality analyses, and waste load allocations all should be completed and ready for use by the time permits addressing the 1983 requirements are ready to be issued. Similarly, planning for the 1983 goal should precede the appropriate construction and permitting actions, and State program development under Section 106 should incorporate the basic planning and analysis.

There will be an increasing emphasis now in other areas in accordance with the water strategy. The first major thrust is to encourage States to develop areawide waste management plans under Section 208. In addition, under Section 303(e), water quality standards and implementation, each shall develop a continuing planning process to provide a coordinated Statewide water pollution control program. Much of the funding for the initial phases shall be Federal. Fiscal year-76 will be a peak year for planning in this area, and the number and extent of plans under development during this period will demand continuing State and regional office attention to assure that the plans effectively address all appropriate elements.

The Agency's initial thrust was to control point source discharges. Now that the permit program is under control, an increased emphasis will be placed upon nonpoint sources. The 1983 goal will not be achieved in all cases by controlling point sources alone. Nonpoint pollution management programs are being developed or have been developed for the control of siltation from construction sites, highway construction, and from silvicultural activities. Pesticide runoff associated with land application and the eventual contamination of water is an area of Agency concern. As established point source control measures begin to take effect, actions should be introduced which address the remaining water quality problems and their causes to determine whether proposed solutions should emphasize further controls over point or nonpoint sources, or some combination of the two.

Two sections of the Act are useful for nonpoint sources management: lake restorative techniques under Section 304(i), and clean lakes demonstration programs under Section 314. Currently, $4 million has been allocated to initiate State clean lakes projects.

Another major program area is the update of water quality standards. This continuing evolution in standards will be initiated with the publication of "Quality Criteria for Water." These criteria incorporate the latest published scientific information and will be used as a basis for developing revised water quality standards. The criteria also will serve as a basis for raw water source criteria used in developing finished drinking water standards. In order to provide a cohesive program utilizing a variety of laws such as the Drinking Water Act, P.L. 93-523, and the Federal Water Pollution Control Act, P.L. 92-500, a single activity can serve a dual purpose; this is exemplified in the use of the "Quality Criteria for Water" for both the 1983 goals for P.L. 92-500 and as the criteria for raw drinking water sources. Another example of a collateral effort is the monitoring data which the program provided for under Section 106(e) of P.L. 92-500. These data can be used for P.L. 92-523 under Section 1431, the emergency powers, for monitoring of toxic or hazardous materials in drinking water.

Approaches will vary in different areas, but some common themes can be identified. Special efforts will be taken in nearly all areas to examine the nature of the urban runoff problem, including storm and combined sewers, and to develop the appropriate strategy and tactics of control.

Public participation is an essential component in developing and implementing water quality management choices. Those who will both pay for and benefit from the activities must have an opportunity to provide inputs throughout the planning and management cycle. Constructive participation, with resulting program improvements, should lead to the public support critical to the achievement of the goals of the Act.

One key to our success will be the extent to which we, as a society, can define and understand the integrity, quality, and behavior of the aquatic environment. We shall need your input and help. This symposium addressing the integrity of water is but one example of the Agency's desire to involve and solicit public participation of diverse interests. I want to thank all of you for coming and helping us.

LEGISLATIVE REQUIREMENTS

KENNETH M. MACKENTHUN
Acting Deputy Assistant Administrator
for Water Planning and Standards
Environmental Protection Agency

The 92nd Congress presented the Environmental Protection Agency with a significant and profound challenge in Section 304 of the Federal Water Pollution Control Act Amendments of 1972. That challenge was to delineate the factors necessary to restore and maintain the integrity of waters and the factors necessary for the protection and propagation of all forms of life that associate themselves with water. It is significant, of course, that the words "restore," "maintain," and "protect" have different connotations in usage and different environmental requirements for their fulfillment. Webster's Unabridged Dictionary defines the word "integrity" as possessing the quality or state of being complete or undivided, of soundness, of organic unity, of an unimpaired or unmarred condition.

We have made every effort to permit intensive discussion of integrity factors in this Symposium with noted speakers addressing physical, chemical, and biological conditions amenable for the best uses of surface waters and of ground waters, fresh waters, and saline waters. Equally important to a series of statements on conditions for existence of water's best uses is an interpretation of the meaning of such discussions to regulatory and planning agencies in governments, to conservationists, to industry, and most important, to the public. In order to achieve success, the identification and delineation of conditions must be followed by implementation through regulation or proclamation, and recognition and acceptance by the public.

Interrelated and influencing factors that affect life in water, the uses of the water, and the users of aquatic life span the dimensions of our knowledge of the aquatic environment. It is a long-established axiom of ecology that the physical and chemical composition of an ecosystem influences the life that may survive and thrive therein and each species that survives or thrives interacts one with another to form the total ecosystem complex. Likewise, the effects on a receiving waterway, either from direct or indirect activities associated with man, have a significant influence on an ecosystem and may increase its relative production of aquatic life or destroy it completely, either for recreation or as an acceptable habitat for organisms. Thus, changes in flow, size, shape, depth, or contour of a waterway; changes in temperature, pH, or relative relationship of chemical constituency; or changes in biotic potential through introduced species, overharvesting of particular species, or misconceived aquatic management practices, may well result in a plateau of accomplishment that is far less than what I believe is a generally accepted concept of restoring and maintaining the integrity of water.

Since investigators began to define the quality of this Nation's waters in the early 1900's, we have recognized a general uniqueness in individual character among each of our many lakes, as well as among major reaches of our rivers and streams. A lake ecosystem in the mountainous terrain of Colorado is far different in the nature and extent of its components from a similar habitat in the agricultural plains of Indiana or Illinois. Judging from an interpretation of some names long attached to lake waters, some such lakes have presented biological problems from the days when the Red Man cooked the profits from his hunt on their shores. Similarly, a fleeting glance would be sufficient for any observer to ascertain a dissimilarity in the potential for life in water between the mighty Missouri and Wisconsin's Bois Brule. Thus, the land over which a waterway flows or the soil over which it resides along with the physical aspects of the water body, determines to a considerable extent the water's potential for biotic productivity. The meaning of water integrity, then, should be adjusted to encompass the range of idiosyncrasies of this Nation's many waters.

The intent of Congress was not that we revert each flowing stream and each lake to its jeweled quality prior to the coming of man on this continent, for that can never be. Man has wrought many irreversible changes to the waterways; the cutting of forests, the plowing of prairie sods, the construction of massive highway systems, and the building of cities have resulted in irreversible changes to the quality of waters that have been associated directly or indirectly with these events. The Western

States' Water Law of Prior Appropriation and the Eastern States' Riparian Law of Water Rights have particularly influenced and affected associated waters. Environmental catastrophies occur and affect water quality either ephemerally or for varying periods of significant time. Floods, drought, ice, wind, and even the recurring seasons have their particular effects that will vary with the intensity of the occasion and with the type of aquatic ecosystem considered.

Man, on the other hand, continues to affect water quality irreversibly and often irreparably with his many actions that result directly in point source pollution or indirectly in and as a contributing factor to diffuse source pollution. Both general sources contribute organic materials, inert silts, toxic pollutants, and nutrients and fertilizers that may stimulate eutrophication. It was the intent of Congress that these sources be managed to control pollution to the maximum extent possible and to restore and maintain water integrity as a result. Other activities that require intensive examination and decision are those that would alter the physical characteristics of waterways, detrimentally affecting their quality. The great natural wealth that originally made possible the growth and development of the United States included a generous endowment of shallow water and waterlogged wetlands which exist as marshes, swamps, bogs, potholes, sloughs, and river-overflow lands. We have come to recognize that the wetland resource, for example, represents an ecosystem of unique and major importance to the citizens of this Nation and, as a result, requires extraordinary protection.

It was not, I believe, the legislative intent that the integrity of water be addressed as an entity separate from the many other mandates of the Federal Water Pollution Control Act Amendments of 1972. No single section of that Act was meant to stand alone. Those amendments represent a comprehensive series of environmental controls and management practices. The unstated goal of Public Law 92-500 is to restore and maintain to the maximum degree possible the integrity of the Nation's waters. The Act provides for grants for research and development, for State pollution control programs, for the construction of sewage treatment plants, for the development and implementation of areawide waste treatment management plans, for basin planning, for lake restoration, and for training. It provides for the development of interrelated standards and enforcement to control the quality of effluents, as well as of receiving waters. These include: the definition of best practicable and best available effluent quality from industries and municipalities to meet the goals of the Act; the development of water quality criteria to provide for water that will support fish and recreation; the adoption of water quality standards; the definition of national standards of performance for the control of the discharge of pollutants for new industrial sources; the development of national toxic and pretreatment effluent standards; the improvement in oil and hazardous substances pollution abatement; the management of vessel wastes; the development of provisions for thermal discharges; the development of provisions for aquaculture; and the development of dredged or fill materials criteria. A comprehensive permit program was established to manage discharges. These legislative mandates all are interrelated with the concerns of this Nation to restore and maintain the best water quality that feasibly can be attained through the efforts of all to focus the Nation's pollution management technologies on that goal.

At every step of the way, P.L. 92-500 mandates a consideration of environmental integrity. The achievement of integrity clearly was considered to result from an implementation of all facets of that law. Planning is a day-to-day factor in our personal lives; wise planning is essential to achieve environmental integrity. Water quality must be of the highest to achieve water integrity. Such quality is provided for in several ways in P.L. 92-500: in effluent limitations that prescribe the maximum degree of treatment technology economically feasible; in ambient quality standards based on scientifically derived criteria that will ensure liberal water uses; and in effluent standards for toxic substances.

Ambient quality standards can be attained only through appropriate treatment of municipal wastes. Again, the Act provides for liberal construction grant funds to build treatment plants, for research to develop innovative treatment or control methods, for the implementation of pretreatment standards applicable to industries that discharge to municipal systems, and for the training of operators to manage complex wastewater treatment systems. As an entity, P.L. 92-500 provides for the process leading toward the attainment of water integrity.

As a society we have become cognizant of the economic impact of each of our actions. This necessity, stated on many occasions throughout P.L. 92-500, often results in difficult environmental decisions. The statutory words ". . . wherever attainable . . ." provide a degree of judgmental latitude. Prudence dictates that there are some individual waters where a purity akin to integrity is not cost effective. Some cannot be restored feasibly. For all waters, however, P.L. 92-500 has become a basis for a national water ethic. Aldo Leopold's clarion call for a national land ethic slowly is being realized for the water.

Aldo Leopold was a giant of a past generation. He met an untimely death in 1948, but in his lifetime he was recognized as a great naturalist, teacher, and conservationist. Writing in "A Sand County Almanac," which was published in 1949 after his death, he admonished his readers to quit thinking about environmental problems solely from an economic standpoint. He wrote, "Examine each question in terms of what is ethically and aesthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." His words of a quarter of a century ago were germane in their time; they remain germane today.

INCORPORATING ECOLOGICAL INTERPRETATION INTO BASIC STATUTES

THOMAS JORLING
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In the remarks of the two EPA representatives preceding me, I didn't perceive what I understand to be the 1972 Amendments; perhaps I should state a little bit about my background with the Act. I served on the staff of the Senate Committee on Public Works during the legislative process leading to the enactment of P.L. 92-500.

It is important to focus attention on one of the most innovative aspects of the 1972 Amendments; namely, the clear, unequivocal benchmark statement of biospheric integrity as the objective of the water pollution control effort. It's significant that it has taken 2½ years for EPA to focus attention on what is the overriding policy of the Act. The fact that it is 2½ years late and all other aspects of the Act are to be implemented under that rubric may account for many of the difficulties encountered in the implementation of the Act to date. I think part of the deep concern I had in listening to the EPA representatives stems from their failure to interpret the specific operational elements of the Act in terms of this policy. I hope to clarify that failure as I proceed.

The benchmark of biospheric integrity is a concept that will have an ever-widening circle of influence and we will see its applicability in many areas of human affairs, domestically and internationally. For instance, as a reference in the consideration of the ozone layer of the atmosphere, the production and use of energy, the movement of manmade chemicals in biogeochemical cycles, and so on. It will extend to providing a framework of making decisions applicable to such issues as contamination of the oceans, interbasin transfers of matter and energy, the supply of materials and water, food production, and even the size and character of our institutions. Yet, it is a difficult concept as the conference topics themselves attest and it is a concept on which the dialogue level should be high.

Prior to 1970, in the case of the Clean Air Act, and 1972 in the case of the Water Pollution Control Act, one would search in vain to find any statement of public policy with respect to the quality of the environment to be obtained under these earlier Federal-State programs. Neither air nor water pollution was defined. The objectives sought were nowhere stated. The regulatory statutes which were in effect at that time were circular, or bootstrap efforts to achieve what, no one knew. But whatever it was, it was to be "feasible."

Prior to 1972, the Water Pollution Control Act was vague on what Congress intended to be achieved. It did not define or otherwise describe water pollution. Rather, the Act stated that its purpose and its programs and procedures were "to achieve the prevention and control of water pollution."

Yet, that undefined notion of what constituted water pollution was further qualified in the Act's enforcement authority where a court, before issuing any final abatement order on whatever water pollution it found, was instructed to "give due consideration to the practicability of complying with such standards as may be applicable and the physical and economic feasibility of securing abatement of any pollution." It is not surprising, therefore, that abatement of water pollution was almost nonexistent under the earlier law.

The purpose of this conference is to discuss biological integrity or ecological integrity in the context of water pollution. I will, therefore, confine my remarks to the Water Pollution Control Act. However, I would be remiss if I did not point out that the ambient air standards structure and the Clean Air Act have very similar characteristics, especially when it is recalled that the secondary ambient air quality standard required to be achieved under the Clean Air Act provides for the protection of ecosystems from any adverse effects. However, acid rain measurements that reveal pHs as low as three and sometimes even below that, are being taken in areas (the northeastern U.S.) where the air quality is superior to the secondary standard, as presently promulgated. Therefore, the secondary standard, at least in the case of oxides of sulphur, is deficient.

In singling out the Federal Air and Water Pollution Control Laws, it should be noted that the deficiency which I have described—the failure of Congress to state what is to be achieved—is not unusual. In fact, in most modern statutes, Congress has not stated with any degree of precision what is to be achieved by the programs it enacts. Rather, it has granted or extended to executive agencies broad, almost unbounded, discretion to determine what they are to do in a particular field and the only statutory reference is to do it within the amorphous standard of the public interest.

This is the root cause of executive branch dominance over Congress. Congress has been deficient in translating the public policy it desires to be achieved into specific norms. Rather, it has shifted the burden of establishing policy to the Executive Branch with few, if any, guidelines or criteria as to what, when, even how public policy is to be carried out. In such a situation, the Executive Branch becomes the forum in which negotiations are conducted, negotiations which really have no clear articulation of the alternatives or the assumptions. Perhaps that is sufficient in the regulation of business practices, consumer protection, and in other areas, but I doubt it. It is clear that such an approach is insufficient when the character of the life support system is at issue.

Incorporating ecological principles into regulatory statutes is not easy. Two quite different sets of problems are involved. The first set might be called philosophical, and the second practical.

In considering the philosophical, it is necessary to contrast the new program enacted in 1972 with the program it replaced because the two provide a conceptual framework in which to compare strongly divergent assumptions. Under the earlier program, the basic assumption was that the biosphere, and in particular the water component of the biosphere, was to be, and in fact existed to be, used. The specific language of the statute reflected this concept and we heard it described in both EPA presentations earlier. The measure of water quality was to be its "beneficial use." Without getting into the debate on the historical origins of the concept of "use" that have been described by Lynn White and others, it is sufficient for our purposes simply to say that earlier pollution control law was based on the assumption that the components of the environment existed to be used by man, a creature that somehow existed apart from and beyond the biosphere.

The new program has a different underpinning. It assumes that man is a component of the biosphere and that relationship we seek to achieve with the environment is what some have called "harmony." Under this view, man is an integral, if dominant, part of the structure and function of the biosphere. The intellectual roots of this perspective are found in the study of evolution. The objective of this concept is the maximum patterning of human communities after biogeochemical cycles with a minimum departure from the geological or background rates of change in the biosphere.

Within the subset of issues under the label "practical," we are looking at the question of whether or not a program which is established to achieve something—a principle, a purpose or an objective—will, in fact, achieve it. We must examine the age-old maxim, is it enforceable? Again, a comparison of the old with the new program provides insight into the tremendous differences relative to practical and enforcement questions.

A program premised upon the establishment of acceptable beneficial uses of water has inherent in it several layers of legal cause and effect relationships that enable easy frustration of enforceable requirements. First of all, there must be some notion, to the point of agreement, on what constitutes a "beneficial use." If we look at the old program we find that beneficial uses supposedly included public water supplies, fish and wildlife protection, agricultural, industrial and other uses. Following the establishment of the beneficial use for the water in question, there had to be agreement on the criteria or scientific numbers for pollutants which would establish and maintain the level of quality of the water which would allow carrying out the supposed use. It should be no surprise that the program did not speak in terms of specific pollutants. Rather, it referred to what, in fact, are effects of pollutants: BOD, chemical oxygen demand, pH, turbidity, suspended solids, and the like. The earlier program included a calculation of "the assimilative capacity" which can be defined as that volume of pollutants which could be processed, treated, or otherwise disposed of in the receiving waters while still maintaining the designated use.

The calculation of such an assimilative capacity assumed knowledge of the structure and function of the aquatic ecosystems over long periods of time, which simply does not exist and will not exist into the indefinite future. Consequently, assimilative capacity became a rather rough, negotiated estimate, often made by lawyers and engineers, certainly not by biologists, of what waste treatment services could be rendered by a particular reach of water. This calculation, or more accurately negotiated agreement of assimilative capacity, coupled with a determination of acceptable beneficial use and an agreement on the specific numbers or criteria, created circumstances in which compromise and indefinite delay operated to frustrate enforceability.

Let us consider, for instance, what was included in any estimate of criteria of water quality necessary to meet a given use. There must have been a prior estimate of the amount and effect of the input of pollutants from upstream waters. There must have been a prior estimate of the cumulative effect of all pollutants on downstream waters, especially the oceans. And we must continually recall that rivers continue to be the most significant contributor of pollutants to the estuaries and the ocean. There had to be a prior estimate of the amount and effects of knowable and unknowable nonpoint sources of pollutants. There must have been a complete knowledge of all components of the waste stream which, as the EPA representatives earlier admitted, is not even known at the present time. There must be complete and accurate monitoring of both the waste discharge stream and the ambient environment, another factor which does not yet exist.

It must be emphasized that all of these estimates were highly amenable to negotiation and to compromise and, more importantly, contained extremely high probabilities of error. It must also be emphasized that all of these estimates would have to be established before any consideration was given to determining effluent limitations or controls applicable to specific sources of pollutants.

Error in any sequential program in which later estimates are based upon prior estimates is multiplied in the final result. So, in addition to concepts such as beneficial use and assimilative capacity, the control program required further logical gymnastics such as the provision of mixing zones which, of course, are defined as those areas of greater or lesser distance around an outfall source in which measurements are not taken. Mixing zones are strictly for the purpose of allowing another layer of negotiation and compromise, always with the burden of proof on the government, the public, and the environment.

The net effect of the program was the application of controls which were fully in accord with and acceptable to the interests of the discharge source. More importantly, the whole program assumed that matter and energy moved in linear pathways. It was fundamentally opposite to the notion of keeping matter and energy within constraining circles or cycles.

The practical aspects of the new program require controls to be set for sources of pollutants without regard to the ambient environment. The control measures adopted are referenced to the present ability to recycle materials, energy, and water within the overall objective of complete recycling systems for industrial, municipal, and agricultural activities. There are, to be sure, opportunities to apply other factors in the consideration of what controls are to be imposed at particular times. The Act is structured so that time itself is the major factor, as performance of sources will be reviewed regularly every 5 years, always under the overall policy of looking towards the reclaiming of pollutants and the recycling of water. It is a happy coincidence when enforceability and the philosophical premise neatly complement each other.

It is appropriate now, almost 2 years and 6 months following enactment of this major change in public policy, to review how it has been received and implemented. Many good things have happened. Perhaps this conference is one of them, late though it is. I will not spend time reciting what good has been done, but rather focus on certain elements of the implementation process as they relate to the concept of ecological integrity.

Here the results are not so good. Let us look at a few specific examples. The first from the municipal waste treatment program. Along about 1900, legitimate concern with disease, especially cholera and typhoid, led to radical change in the view of municipal waste in this country. Prior to that time, the perspective, where there was one, was generally compatible with modern ecological principles. However, at about that time and in large part continuing through to today, our efforts at handling municipal waste shifted to a policy that can be characterized as chlorinate and dump. This notion, incidentally, based on the premise that the natural water systems perform waste treatment services, was greatly facilitated by the program of pollution control in effect prior to 1972.

Possibly reflecting the rural character of our population before 1900, it was common to incorporate sewage through the application of such "waste" to the land and agricultural activities—so-called sewage farms. In a word, nutrients of high value were returned to the biogeochemical cycles from which they came. Even in large communities, such as Berlin, Paris and Melbourne, sewage systems had this characteristic.

In an ecological context, they make sense. But the sense they make cannot be made clear unless the components of municipal waste are broken down into their specific biological, chemical, and physical characteristics, a trilogy of words that appears often in the new Act.

Thus, under the 1972 Amendments, the EPA Administrator was given 1 year to translate the old sanitary engineering notion of secondary treatment into a definition conforming to the requirements of the 1972 Act: specifically, to write an effluent limitation at the level of performance achieved by secondary treatment, as defined in Section 502, a restriction "established by a State or the Administrator on quantities, rates and concentrations of chemical, physical, and biological and other constituents which are discharged from point sources into the navigable waters."

The Administrator, after the lapse of more than a year, promulgated an effluent limitation for secondary treatment which was written in terms that could have been written in the 1920's. Secondary treatment was defined on August 17, 1973, in terms of BOD, suspended solids, pH, and fecal coliform content. Such a definition reveals no understanding of the ecological character of municipal waste. BOD is not a pollutant, it is an effect of a class of pollutants of organic character.

Municipal waste is comprised of, among other things, phosphorus, potassium, and nitrogen, the standard nutrients of commercial fertilizer. These materials should have been incorporated into a new ecological definition of secondary treatment. Yet, this was not done and has not yet been done.

Similarly, since municipal waste is, by the promulgated definition of EPA, considered to include only those things which cause the effects recited in the definition, there is no recognition of the fact that many exotic chemicals, including heavy metals and pathogens, are working their way into the municipal waste streams as a result of the use of such materials in industrial operations, hospitals, and even in household cleaners and the like.

Until we move to the identification of the specific biological, chemical, and physical constituents of the municipal waste stream, we are not going to be given the conceptual framework in which to move towards recycling.

More ominous than the activity of EPA in defining the secondary treatment effluent limitation has been the interpretation of the Phase II or 1983 requirements for municipal waste treatment systems. These are termed in the Act as the "best practicable waste treatment technology." Under the Act, as recited in Section 201, these requirements are to provide for "the reclaiming and recycling of water and the confined and contained disposal of pollutants so they will not migrate to cause water or other environmental pollution."

Rather than promulgate a specific effluent limitation for the specific and different systems that meet this test, EPA is now defining the Phase II requirement in what can be characterized as an ambient water quality standard.

This failure of EPA to translate the municipal waste treatment requirements specifically in terms of recycling flies in the face of the Act and is potentially the most damaging aspect of implementation. If continued, it will prevent any restructuring of society in accordance with ecological integrity. One would hope that as the Agency continually evaluates its position it will act in a manner more consistent with the spirit and the letter of the law.

A second example. Many States and the EPA are issuing permits under Section 402 which speak in terms of mixing zones even though the definition of effluent limitation under the Act does not admit such a concept. The Agency continues to opt for escape from enforceability which the mixing zone represents. A mixing zone always affords an alleged polluter the defense that it was not his effluent which caused or contributed to the violation at some arbitrary circle around an outfall, but rather, to plead and shift the impossible burden to the government and to the public, that it was the upstream waste load, or even the flow characteristics of the stream that caused the pollution.

Mixing zones are inherently unenforceable. In fact, under the Enforcement Section, Section 309, there is no statutory authority to enforce such provisions.

Perhaps the most important aspect for the ecological notion of reincorporation of matter and energy into biological cycles has been woven into the Act in Section 208, the Planning and Management Section. In part, this process should have been viewed by the Agency as an educational opportunity for the citizens of this country. I might add here that before educating the citizens of the country, I would have hoped that EPA would have sponsored within its own structure and for its own personnel a program similar to the Water Quality Institutes for citizens that were sponsored by the Conservation Foundation throughout the country. I think it's very important that everyone be educated to the new concepts that are in this Act.

We have come a long way from our rural tradition, where experience with growing organisms was a part of everyday life, to the point where a great majority of our citizens live in urban concentrations and have no experience with living systems. Food, energy, and housing tend to be viewed in such a culture as simply technological products. So also the management of waste. Yet ultimately, all of these life support requirements are drawn from and have their source in the biosphere.

Section 208 provides an opportunity of great significance to view human habitations from the perspective of ecological systems, to incorporate nutrient material back into the cycles from which they came, and to prevent the escape of exotic chemicals. However, as part of the general resistance of this Agency and the Administration to Section 208, this educational opportunity has fallen by the wayside. Our urban citizens are not being given information concerning the nature of so-called waste material and the possibilities of including it in the production of, for instance, foodstuffs. Rather, they are simply told that the waste treatment problem is an engineering problem. "Pour concrete on it" is the message.

Food, energy, and materials are all being produced at greater and greater distances—geographical and technological distances—from our people. Such remote systems make population centers very vulnerable to disruption and hostage to systems of delivery.

The water pollution control program could have provided a counterpoint to such trends. It could and should enable us to look at the structure and functioning of human communities, much as we look at natural communities, in terms of biogeochemical cycling. We could and still can, under the Act, move in these directions.

In addition to the specific areas where implementation has failed to live up to the promise and purpose of the 1972 Amendments—the policy of ecological integrity—there has been a growing trend to impose so-called balancing, tradeoff, or benefit cost analysis in establishing goals, objectives and other requirements under the Act.

Cost and benefits are inextricably a function of the system in which they are applied. They operate as positive and negative feedback mechanisms to keep the system on the course on which it is embarked, whether or not we know where it is going. Perhaps here it might be useful to add what I think is an accurate description of where our system is going. It comes from H. G. Wells' lament in the classic paper, "Mind at the End of Its Tether."

"Everything was driving anyhow to anywhere at a steadily increasing velocity."

Simply put, applying costs and benefits assures that society will not materially change; for, by definition, any change which would cause a significant alteration in any pattern of the existing society in terms of employment patterns, altered consumer patterns, reducing or limiting the amount of capital or its return, or whatever, is an unacceptable cost.

Thus, applying benefit and cost analysis assures that our society will not change. The crucial question is whether the crusade to benefit cost or balance every decision, especially decisions relating to public policy objectives, will do anything more than improve the efficiency of the society in moving along its course. My answer is, probably not. That is, not until society comes to terms with at least some basic elements of its destiny. Benefits and cost should determine means, not ends.

The 1972 Amendments' Statement of Ecological Integrity is a statement of ends. That is, what is to be achieved. Put this way, it provides perspective within which to make judgments about our future. It provides a planning and a regulatory mechanism. It provides an opportunity, if we use it, to look at the structure and functioning of human communities as elements in the overall biosphere and make judgments about the life support requirements of those human communities.

This is a tall order. Yet it is the direction in which we must move; it is the legacy of the concept of ecological integrity.

DISCUSSION

Comment: Under CFR-133, our Agency has defined secondary treatment in terms of effluent levels; that is, for BOD, suspended solids, and microbiology. There is an effort afoot now to remove the microbiological effluent level from that definition based upon the justification of conflict of beneficial uses and energy requirements. I'm just wondering if you would like to say a little bit about that.

Mr. Jorling: Curiously enough, the fecal coliform is the only specific pollutant which is included within the definition. It is something which is discharged and is measurable specifically. I suspect it's not just coincidence that it is a specific pollutant and that there are attempts to remove it from the definition.

With that much said, I'm still concerned because I do believe the singular attention to fecal coliform is unnecessary. There should be attention towards all the pathogenic materials in the municipal waste stream. But such attention should be referenced to specific pathogens and not so much to *E coli*. Of course, it's an easily identifiable bacteria and we had, back in the early stages of public health, the ability to test for it. Then followed guilt by association—if you found *E coli* you also had cholera and other potential disease causing organisms.

I think we should go beyond that stage now, placing less emphasis on fecal coliforms and move to other systems of waste treatment management and focus on the more commonly known and also more pathogenic materials in the municipal waste stream.

Comment: How do you protect the integrity of the ground water with application of land treatment systems? Are the two integrities compatible?

Mr. Jorling: I believe so, with effective management. I don't think if you're considering reapplication of waste water to agricultural, aquacultural, silvicultural, or other activities, that you just indiscriminately apply that waste to the soils. What you do is make studies of the particular climate, geological factors, and soil formations you are working with and include within those calculations ground water considerations.

I don't think there's anything incompatible between the two. Properly managed, a system of reapplication of waste water to the land can be done without jeopardy; in fact, it can enhance, in the sense of not depleting, the groundwater system.

Comment: Do you think that a significant retooling of what is now the sanitary engineering community would be required before any significant move to the recycling system with regard to municipal waste?

Mr. Jorling: I guess, to be honest, a brief answer to that question would be "yes." The sanitary engineering community, primarily the consulting engineers who advise the communities around the country of what their problem is and how to solve it, has long, tenuous roots in water pollution control. It goes back to the problems with disease that I mentioned in my statement and the chlorinate and dump philosophy. Retooling is a difficult thing to achieve in any situation. I would hope at least educational efforts would be undertaken. Yet, from the perspective that I now observe the program, that is, from a community that's trying to put in a waste treatment facility, it's obvious that there is nothing from the top coming down to the regional offices, to the States, or to the communities with respect to these concepts.

Rather, the attitude is still, very simply, pour concrete on it. Pull out the old form for a secondary plant, like a lawyer pulls out a will, and build it. That's what we still observe. So we do need a tremendous amount of innovation and education within the structure of the water pollution control program as well as what I suggested, which is an educational effort among the citizens of the country on what their life support needs and requirements are.

Comment: I'd just like to comment on this exchange that took place. In Illinois we have had over the past few years at least two significant major proposals for wastewater recycling or some form of recycling of municipal waste on a large scale. One of them has been implemented by Metropolitan Sanitary District of Greater Chicago in their prairie plant. The other, the infamous study of the Chicago District Corps of Engineers has not been implemented and, I think it's safe to say, won't be. In both cases, these are proposals that have been made by the sanitary engineers and have run up against a great deal of extreme resistance, not by the urban people who are generating the waste, not by the technical people who must design the system, but, surprisingly enough and I think counter to your comment earlier, by the rural residents who don't want that Chicago waste material deposited upon their farm lands. Would you care to comment on that problem?

Mr. Jorling: I'm not as familiar with the circumstances of this as you are, but I do recognize the accuracy of your comment that the opposition was generated in the northern areas of Indiana. I'm not sure that the reaction had its initiation with the rural residents as much as it had with some of the political representatives of those people. Once the momentum of reaction was established it was impossible to reinject rationality. It became impossible to consider what the material was and what it could represent. I think, also, the Corps of Engineers and the Environmental Protection Agency instead of operating in diverse directions when that study was being performed could have worked in harmony with the 1972 Act and could have overcome a large measure of that opposition in advance instead of just standing above Northern Indiana, as it were, proposing to drop all the waste of Chicago on it, unbeknownst to the people of Indiana. Until that time there could have been much more working with people. Section 208 incidentally, provides that vehicle.

INTEGRITY OF THE WATER ENVIRONMENT

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Nearly 10 years ago there was another "integrity" conference here in Washington.[1] While the subject of that conference, The Integrity of Science, dealt with a very different issue, there are some interesting threads leading from it to our present meeting. Barry Commoner, in speaking of the issues touched on in The Integrity of Science, said,

> There are serious disparities between the traditional principles of science and modern realities. Perhaps the old ideals are no longer valid, and the present departures from them are a successful adaptation of science to its new position of power and importance. Or are the traditional principles of science still applicable? And in any case, what are the consequences of the growing tendency to encroach upon them? Does this tendency weaken science and impair its technological usefulness; could it cause some of the evils which seem to follow so closely on the heels of modern scientific progress?[2]

We have seen science assume a greater role in our lives and become a powerful political force. At first the change was manifested in the adoption of new technologies, with the engineer assuming increasing importance, then the physicist, the biologist, the chemist. In the past decade a new discipline has risen to a preeminent role in charting the course of political action both through shaping public opinion and through direct political action—that discipline is ecology.

Another alteration in the role of science in our society results from the conflict between the increasing rate of societal and technological innovation and the time available for research. Scientists must perform the necessary experiments to observe and measure the effects of such change and innovation. But, while we have been very busy observing, noting, and quantifying, we find that the informational base needed to cope with present knowledge demands is sadly lacking. Joel Hedgpeth has suggested that "the search for simple approaches and magic numbers that may be obtained with relative ease has led some pragmatic ecologists down the primrose path of theoretical ecology."[3] While I do not really relish initiating a debate on the subject of theoretical ecology, it does seem to follow that scientific method may be responding to the pressures for immediate analysis of environmental change. How else could such wonderful expressions as pre-site survey and post-site survey have entered the vocabulary of even the undergraduate student?

The need for data is clearly outstripping the ability of science to produce. As a result, scientists now more frequently appear in the public forum to argue a case without the conclusive factual information required by them some years ago. The simple fact of the matter is that decisions affecting our lives and our futures are being made each day. Unless we who have technical information, or even "educated opinions," participate in those decisions, we shall not be able to look back and be critical—there may be no point from which to look back. The increasingly important role of technical information in decisionmaking results from the technological explosion brought about by scientific advance. We cannot abrogate our responsibility for participating in making decisions about our lives and our futures.

Our present seminar concerns integrity of water. We are called upon to address this subject because of the federal legislation entitled Federal Water Pollution Control Act Amendments of 1972, which states in its Declaration of Goals and Policy: "The objective of this act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Walter Westman reviewed the debates that led to the wording of the act:

> Controversies surrounding the drafting of water pollution control legislation are often based on differences in the ultimate water quality goals sought. Less obviously, but no less importantly, the controversies are usually rooted in fundamentally different methods of conceptualizing the nature and behavior of pollutants. These differences are of crucial significance, since they have influenced the strategies for legal control of water pollution not only in the United States but in many other parts of the world. . . . I will . . . [use], for want of better terms, two rather emotion-laden words to characterize the viewpoints: technological and ecological.[4]

The importance of what we are about in these 3 days rests not only in our specific charge, the discussion of the meaning of integrity as it is applied to the Nation's waters, but also in a fundamental issue of the responsibility of science. The Federal Water Pollution Control Act Amendments of 1972 contain a basic philosophical shift in water management from one of standards (technological approach) to one of integrity (ecological approach). This is a significant achievement.

Science has a new set of responsibilities, some of which my colleagues do not feel comfortable with. I believe that Barry Commoner's words on the integrity of science are useful to us today, but in a different context. Science has a new responsibility, one not often faced up to—that is, the responsibility for assisting, more than ever before, the amorphous group we academics tend to lump together as "decisionmakers", in making decisions which affect us all and in taking action in the absence of information and data. In doing this, we step outside the traditional conservatism of science and enter into a role emphasizing the disparity between "traditional principles of science and modern realities." Our purpose is to work toward a definition of integrity that will allow its application in regulating the Nation's waters.

I am somewhat awed at being the first of the speakers from the scientific community, surrounded as I am by some of the leading ecologists in the country. My own knowledge of water quality and aquatic ecology is limited. My present role as a director of a Sea Grant program has placed me in the context of a pragmatist concerned with the development of the resources of the marine environment and only indirectly with the question of water quality and its monitoring and regulation. Those of us who deal with the marine environment, however, are rapidly becoming highly sensitized to the rapid decay of the quality of that last repository of wastes—the oceans. Within my own State's waters, we have two outstanding examples of the uncontrolled impact of man: Lake Erie and New York Bight. We have also seen, in New York State, the response of citizens and of the aquatic environment itself to a vigorous program of water quality improvement—a dramatic change in ecological, social, aesthetic, and economic values.

A small Sea Grant-sponsored study of the property values of Chautauqua and Erie Counties in New York showed that from 1955 to the present, land values along Lake Erie did not increase (in constant dollars), while those of small, "pristine" (but ecologically threatened) Chautauqua Lake increased over fivefold.[5,6] Other economic factors such as tax revenues, employment, and recreational utilization are similarly linked to the perceived value of the aquatic resource. Popular attitudes can be changed and are changing in the region mentioned as citizens become aware of the revitalization of a resource. There is, therefore, an economic and social return to be obtained from improving water quality.

The real issue is, however, much more fundamental and far-reaching. Some set the issue at the point of survival for the human species. In this context, it might be well to look for the antecedents of the concept of integrity as applied to water regulation. It is my understanding that our colleague George Woodwell proposed this concept in a letter to Senator Muskie in 1971. I am certain that one can trace Dr. Woodwell's concern far back through his prolific writings as well as follow its expression forward in some of his latest articles. Dr. Woodwell's basic argument, as I see it, is that we are really addressing only one aspect of the fundamental problem when we look at water quality. We are seeing only a part of the impact of man's burgeoning population upon the life system of this planet. In the public mind, the population issue has taken second place to the immediate problem of energy supply. The preeminent concern today is the human activity generating energy. Woodwell has stated:

> There is a common tendency to think of pressures on the environment as directly correlated with the growth of population; and so they are. The population of the earth is expected to double in the next 30 to 35 years. But pressures on the environment are also a product of human activities.[7] . . . there are abundant signs that growth in human influences has already progressed to the point where . . . individually small insults are worldwide . . . we are changing the physics, chemistry, and biology of the whole earth, a clear sign that growth in the aggregate effect of man has already exceeded the point where we can rely upon the classical assumptions about further growth.[8]

We are fortunate that a colleague, Walter Westman, was involved as a "full-time ecological advisor" during the drafting of the Federal Water Pollution Control Act Amendments of 1972, and even more fortunate that he did us the great service of summarizing that enterprise from the viewpoint of the ecologist.

I should like now to review the fundamental change that occurred in water quality legislation, and I shall lean heavily upon Dr. Westman's article in so doing. Westman usefully contrasted what he termed the "technological approach" and "ecological approach" to water pollution control in five legislative "issues": water quality goals, mode of treatment of pollutants, mode of classification of pollutants, mode of monitoring the success of pollutant removal, and the legal point of control.

ISSUE ONE—GOALS

Tom Jorling has already pointed out that one of the great deficiencies of previous attempts to control water pollution was the absence of a clearly stated goal. In so doing he stated what might be called an "ecological imperative"—that is, it is imperative for ecology to be utilized. Jorling said ". . . due consideration to the practicality of complying with such standards as may be applicable and the physical and economic feasibility of securing abatement of any pollution." The 1972 Act, however, clearly states that restoration and maintenance of the physical, chemical, and biological waterways shall be its goal. This, of course, contrasts with previous definitions, which were couched in terms of man's uses of waterways. This change sets a higher goal, which, I am sure it will be argued, places an unnecessarily high cost upon society. Many take the contrary position on the basis that the natural state has the ability to maintain itself without the technological intervention of man, in itself energy consumptive.

Also embedded in this statement of goals is the change in thinking with regard to the concept of "assimilative capacity." Ecologists argue with considerable force that there is no assimilative capacity, that any additive has some effect upon the system at some point—immediately or in the "far field." We have difficulty in predicting the fate of pollutants. John Cairns has stated: "Anything added to or removed from natural waters will probably cause some change in the system, whether naturally or by the activities of man. Our perception of these changes is limited by the precision of our assessment methods and by the limited background information on the structure, function, and rate of change of natural systems."[9]

Westman called attention to the inadequacy of the human-use approach to water quality standards: "This kind of assumption [assimilative capacity] is made throughout any use-classification system for streams, almost invariably without a detailed foreknowledge of the fate of pollutants in the stream." We are continually plagued by the absence of knowledge or data; we cry out that we cannot answer the question—yet. As we move from the concept of assimilative capacity, and its corollary human-use standards, to the concept of integrity, we will have to answer the question of what integrity is. I am sure that we shall also be asked, how do you measure it?

My esteemed colleague, the peripatetic marine ecologist Joel Hedgpeth, in writing on the Impact of Impact Studies, called attention to the problems caused by our own uncertainties about natural biological systems. He said: "From the more practical viewpoint, however, the requirement that the potential effect of projects upon the environment be estimated has produced a confused ferment of ecological studies in which still untested theories may be frozen into bureaucratic procedures and inadequately trained personnel may be canonized as consulting ecologists."[10]

ISSUE TWO—MODE OF TREATMENT OF POLLUTANTS

The ecological approach to the problem is, of course, to eliminate the discharge of wastes into water bodies and to emphasize the recycling of wastes and the utilization of land-use controls for the nonpoint sources. Unhappily, although some claim that answers to this approach are at hand, there are many yet unsolved problems, and we find that in several cases there is not yet a "technological fix" but rather only a movement of the "problem" to yet another point in our biosphere.

Have we indeed removed the source of pollutants? Are we truly recycling? Or, are we causing new and as yet unrecognized problems? Many of you here today will say that the answer clearly lies in recognizing the fundamental fact that we may have too many people, too many chemicals of unknown character and behavior. It is manifestly simpler to remove materials from discharges before they enter the natural system than it is to track them through the system and follow all the new combinations, linkages, and synergisms that occur. I recall a colleague in a large firm which plated and otherwise pickled metals. In a spirit of environmental consciousness he volunteered to work, on his own time, with the company to reduce their waste discharge. He was led to the large tank at the end of the processing system into which all the pickling waters were drained and told, "There's the raw material, go to it!" To his horror he found that the slurry in this tank was the combined wastes of six different metal treating process lines. The slurry was incredibly complex and boggled his chemical-engineering mind. His suggestion that the wastes from each of the six processes be accumulated separately and "reclaimed" individually was greeted with cries about the expenses of repiping and new construction. While my tale is admittedly drawn from the old days—perhaps 6 years ago—the fact remains that treatment at the source is less expensive than treatment farther downstream; treatment by elimination of the product itself from our society may be the final answer.

Not all share my viewpoint that engineering is more an art than a precise science. But I believe the critical question we must ask with respect to treatment of pollutants through recycling is—can we do it? Tom Jorling has argued that we are not even progressing on the regulatory front.

ISSUE THREE—CLASSIFICATION OF POLLUTANTS

Westman states that the classification of pollutants under the ecological approach may be dealt with by measuring their effects upon the biology of the receiving waters. He divided pollutants into four categories: nutrients, nonnutrients, toxic substances, and pathogens. Nutrients were considered in terms of their potential to accelerate eutrophication; nonnutrients were those materials that would not be transformed within 1 week and that would have principally a physical effect upon the receiving waters. He recognized, however, that nonnutrient pollutants had a particularly important characteristic in that they contained many materials of unknown future activity and that many might be better classed as toxic substances. He defined toxic substances with consideration for the concentration at which the substance was active. Exposure, ingestion, inhalation, or assimilation of substances that could cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, or physical deformations were the basis for including a substance in this category.

Woodwell has, on the other hand, argued that standards for toxins cannot be set on the basis of thresholds for effects; our capability to measure thresholds is inadequate for the bewildering variety of substances that can be released. There is no way to control releases or to monitor substances released. And there is "little basis for the belief that natural thresholds for effects on natural ecosystems exist." [11]

ISSUE FOUR—POLLUTANT REMOVAL

The success of pollutant removal under the ecological approach is to be monitored biologically in the stream, as contrasted with the technological approach of monitoring effluents in-plant. This approach will require observing the health of organisms in the stream at every level of the food chain. Hedgpeth stated, with respect to the National Environmental Protection Act, an argument equally cogent here:

> This requirement of impact studies that in practice must meet the scrutiny of hungry lawyers advised sub-rosa by some of our better ecologists, should have an especially salutary influence upon field studies in the coastal zone. . . . So far, these studies, intended to produce "base line" information, have not been impressive, primarily because of the reluctance of the industries and agencies concerned to finance them adequately, and secondarily because the work has been carried out by consultants and assistants lacking the training or understanding necessary for such work. Yet, insofar as studies relative to possible environmental changes in the shore zone are concerned, we have known what should have been done for more than 100 years, and for at least [illegible] years have had some sound advice available even in plain English.[12]

Clearly, it is this aspect of the ecological approach to water pollution control which will require the greatest effort by the scientific community if the approach is to work.

ISSUE FIVE—LEGAL POINT OF CONTROL

The ultimate pitfall of the technological approach to control was that it required the enforcement agency to be able to predict the effects an effluent would have upon the body of water. The complexities that factor into such a capability are somewhat greater than science has been able to master.

In the ecological approach, Westman insists, the dilemma persists. The goal is to achieve the integrity of the physical, chemical, and biological characteristics of the water. It is tacitly assumed, at least to my mind, that only pristine waters possess integrity, for in these waters time and evolution have interplayed to produce a fauna and a flora adapted to the natural characteristics of their environment. Westman argues that to allow anything short of this leads again to the uncertainties of relating effluent composition to effluent effects upon water quality. It was this reasoning which led Congress to state: "It is the national goal that the discharge of pollutants into navigable waters be eliminated by 1985. . ." The means to meet this goal is closed-cycle technology.

We insert at this point the complicated question of our ability to solve the problem technologically, the economic costs of accomplishing the objective, and the alternative or "tradeoff costs" of not doing something.

As pointed out in the preceding paper, the 1972 Water Pollution Control Act set a clear objective in the statement of goal with which it was prefaced. The Act proceeded further to make some clear statements establishing the mode of getting to the objective. One might ask, however, how do we measure our success or failure in meeting the objective, whether that success or failure be legislative, interpretive, regulatory, enforcement, technological, or other. If we measure progress toward the goal through the character of the biota of streams, are we not simply looking at "assimilative capacity"? Are we not, if we examine only the point downstream of discharge, perhaps oversimplifying the problem, for the effect may simply have moved farther downstream. To use a homely example, much of the upper Hudson River has "improved" in water quality to the point where it is now "safe" for use by humans for a variety of recreational purposes. The root causes have been transferred, however, to the substrate and to the downstream reaches. There is a cosmetic character to improved water quality which causes relaxation of vigil and effort towards improvement.

On the other hand, we can measure our failure to achieve the goal stated in the Act by observing further degradation. As a group of scientists, we have not achieved a clearly stated consensus on the limits of further degradation. I do believe that a clear majority feel that we are approaching the limits of our ecosystem and I further believe that many citizens are equally aware and concerned about those limits. Tom Jorling has spoken eloquently of the failure of the Environmental Protection Agency to capture an educational opportunity to identify the need to reincorporate nutrient materials into the ecosystem and the cycles from which they were derived. This is clearly not an engineering problem, for if it were, we would have substantially moved toward its alleviation.

I cite as an instance the vexing question of sludge dumping in New York Bight. Faced with disposal of a potential nutrient (I simplify here, for the removal of toxic materials from the sludge is indeed a technological problem), many engineers, scientists, governmental administrators, and most citizens view the solution solely in terms of moving the dump site farther from the shores. If indeed the educational opportunity had been seized, public hearings on the dumping of sludge would now be filled with clamor and furor over the technology of recycling, not, as at present, on shifting the site.

The matters to be discussed in this conference on The Integrity of Water are many and complex. I wish that I could offer some simple resolution to the problem. I am, however, only able to fall back on the anecdote recounted by John Steinhart: "A prominent economist was addressing a meeting of economists, taking them to task for their enormous self-pride in being hard-headed in dealing with world problems. He suggested that they weren't as hard-headed as they thought and he offered them a succinct solution to the world's problems—economic, environmental, and otherwise. His suggestion—"eat rich people." [13]

Steinhart urged us to think about it—the process of continually lopping off the top of the pyramid. Steinhart suggested that "the somewhat didactic moral is that morally acceptable solutions are not guaranteed from analysis." [14]

Better guidance may have been given by our colleague at this meeting, John Cairns, who concluded: "Predicting and judging environmental impact with precision are areas in which biologists must excel. . . Good management is always preferable to "fire-fighting"! Both biologists and industrialists will have to be more flexible if we are to preserve some of the desirable qualities of life on an over-populated planet." [15]

I began this discussion by referring to an earlier conference on The Integrity of Science. I should like to quote from some of its findings:

> . . . the ultimate source of the strength of science will not be found in its impressive products or in its powerful instruments. It will be found in the minds of the scientists, and in the system of discourse which scientists have developed in order to describe what they know and to perfect their understanding of what they have learned. It is these internal factors—the methods, procedures, and processes which scientists use to discover and to discuss the properties of the natural world—which have given science its great success. We shall refer to these processes and to the organization of science on which they depend as the integrity of science.[16]

My closing observation is that our Nation is now in the midst of a turmoil caused by immediate problems—the economy, energy supply, and a host of other heatedly debated subjects. We must not lose sight of the larger issues, however. Bentley Glass, addressing the "Goals of Human Society," summed it up thus:

> The study of the limits of man's resources on earth—the limits of energy, atmosphere, water, soil, foods, minerals, and fuels, and species of utilizable organisms—should be coupled with a vastly improved basis for technology assessment. . . The cry will be made that such a system would greatly retard the introduction of innovations in modern enterprise, would reduce profits, halt economic growth, and put an end to 'progress.' That may well be so. The shibboleths of an ever-expanding economy and of never-ending growth have deluded modern man long enough. With such clear signs that we are pushing to the limits of the earth's resources in many ways, perhaps we are ready to recognize that human progress in well-being is not synonymous with greater numbers of people or steady increase in the rate of exploitation and pollution of the environment.[17]

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DISCUSSION

Comment: With the remarks we had this morning, I wonder if, in a sense, we aren't using the terms physical, chemical, and biological integrity to help escape the real intent of the law. Speaking as an ecologist, I have to make a confession, at least from my personal point of view: we ecologists still have not graduated to the level of science that chemists and physicists have. Our paradigm is not that clearly defined. In a sense the term "integrity of the system" would seem to me to be almost a cop-out because what the law states, and correct me if I'm wrong, is that we are taking a look at our Nation's waters from essentially an historical perspective, trying to get back to that kind of environment or that kind of ecosystem that was present before pollution occurred. That, in fact, is a value that is not a result of scientific thinking along this particular line. We can, I think, rationalize from an ecological point of view that Lake Erie from the time it was first explored by the French warriors to the time that it reached its highest level of eutrophication was, in fact, a physically and chemically and biologically integral system. It had its integrity from a functional point of view. It worked. It functioned. It did not die. I wonder just how much we are confusing the issue with some terms that perhaps should be looked at in a somewhat different perspective than we have in the past. Perhaps one of the reasons that we failed in the education process is essentially that we really don't know what we're talking about when we talk about integrity in terms of its application for a set of values.

Dr. Squires: I'd enjoy an opportunity to speak to that because I think there is an element in your premise that I would argue with. I don't think that the concept of integrity needs to be one of returning to a previous state. That would indeed mean that we would not only have to eat rich people but a great many others.

What we really have to look for is a means by which we can preserve natural systems, and, by that I mean physical, chemical, and biological systems, at a level which provides us, the human species, with a means for survival. We have to do this in a way which is least consumptive of energy. I think a pretty rational case can be made that better treatment of pollutants prior to their being placed into any receiving body of water is less consumptive of energy than it is to try and maintain the integrity of the system once you have polluted it.

I think that's the key issue. Do I depart from your thinking?

Comment: No, not at all. However, I would say it is an expression of a set of values that we're trying to describe, too. I think someone mentioned or referred to, Aldo Leopold and the ecological and conservation ethic earlier this morning. This is really what we are talking about—its application.

Dr. Squires: Again I want to return to the point that the most impressive part of this particular piece of legislation is that a goal was stated. Without a goal one has no direction in which to move, one has no ability to set forces at work to make progress and one has no way to measure one's progress towards achieving the goal. The fact that a goal has been set is the most significant thing done in this particular piece of legislation. Whether or not we can achieve it and how we go about achieving it are subjects for discussion. But the fact is that the goal is compatible with the very simple factor of survival—that's the key.

Comment: I have no argument with that.

Mr. Jorling: It's certainly a value judgment to establish integrity and the value is prudence, I suspect. Given that we don't know much about the biosphere, where can we look for wisdom? What the integrity standard does is to say that we measure what we do against a background. In other words, we're trying to establish a reference point for the measure of what man is doing to the environment because by and large we don't know this. Every time you pick up another issue of Science, there is something buried back in the notes that talks about freon and what have you. There are so many things that we're doing to the environment for which we just have no reference point. So, the integrity statement establishes that reference point.

The value of prudence is that it's easier to remedy smaller defects than big defects so that if you screw up the Hoosic River, it's easier to fix that than screwing up the Hoosic and the Hudson; or worse, the Hoosic, the Hudson, and the Atlantic Ocean.

With our capability to manipulate natural systems, where is our effect the greatest? It's on smaller systems. We should keep things patterned after natural systems; the more closed the material energy cycles within those systems, the better, so I think that's another value judgment. It recognizes our limitations.

CHEMICAL INTEGRITY

THE WATER ENVIRONMENT

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Earth is unique among the planets of our solar system in having an abundance of water in the liquid state. This is unquestionably a consequence of the evolution of the planet and of our favorable location in relationship to the sun. While other planets may have large masses of ice and, undoubtedly, waters of hydration associated with the lithosphere, none has a true hydrosphere which is characteristic of the earth. The presence of this liquid water has enormous implications for the evolution of life as we know it on earth, including the human species. Thus, there is more than one reason to hold this conference on the integrity of water. For without water there would be none of us here to discuss it and, next to the air we breathe, water is the most critical substance to maintain life.

Even on earth the majority of water is sequestered in the primary lithosphere and in sedimentary rocks, primarily as water of hydration. The water tied up in this way is nearly 20 times as great as the free water that we are discussing here today (Hutchinson, 1957). Water is being added constantly to this reservoir by volcanic eruptions and by hot springs, but it is still uncertain how much of this is truly juvenile and how much is derived from the hydrosphere already present.

In looking at the title of my talk, some of my friends suggested that I have the whole subject to cover. I don't pretend to cover the whole subject.

The present distribution of water in the hydrosphere is shown in Table 1. As an oceanographer, I will speak primarily about the 98.8 percent of this water which is found in the oceans and I am pleased that others will speak about the surface water and ground water resources, the principal sources of drinkable water. The smallest fraction in Table 1 is the water vapor of the atmosphere which may, nevertheless, be the most important. Because of the great mobility of the atmosphere, the precipitation part of the hydrological cycle is greatly dependent on this small fraction of the free water on earth. The evaporation from the ocean surface exceeds the precipitation there, and this provides for the excess precipitation on land surfaces, nourishing plants and giving the continuous flow of our rivers and recharge of our ground waters. In this and many other ways, the linkage of the ocean and the atmosphere exercises a profound control on the climate of earth.

Table 1.—Free water distribution on earth.

Location	10^{14} Metric tons
Oceans	13,800
Polar and other ice	167
Inland water	0.25
Ground water	2.5
Atmospheric water vapor	0.13

Data from Hutchinson, G. E. 1957. p. 223.

Over the eons of geological history, this hydrologic cycle has been weathering the land and carrying the elements into the oceans where they have accumulated. Seawater contains, on the average, about 3.5 percent solids and virtually all of the natural elements are present, though some in trace amounts. Of the latter, some have been measured only very recently as a result of the refinement of our chemical methods of analysis. As a broad generalization the major elements in seawater are present in constant relationship to one another so that seawater can be considered as a solution in which the main variable is the total quantity of water. Evaporation can increase the salinity, or total salt content of the water, and precipitation can decrease it, but the elements present remain in substantially the same proportion one to another. Minor perturbations occur near the mouths of rivers where the chemicals of the river water can modify this generally constant relationship among the major elements. In the deep waters of the sea, however, which constitute almost three-quarters of the oceanic aquatic reservoir, the composition of seawater is the result of many millions of years of equilibration with the land, and man's activities have yet to produce a measurable effect there.

Some of the minor elements in seawater are essential for life. These include carbon dioxide, oxygen, nitrogen, phosphorus, and for diatoms, silicon. The growth of microscopic floating plants, the phytoplankton, is limited by light intensity to the surface layers of any aquatic ecosystem. These life processes vary the concentration of these elements and compounds, sometimes exhausting the supply so that further productivity is inhibited. The near-surface photosynthetic production of organic matter supports all life in the open sea, but it is in these same waters where man's activities are having a measurable impact. This is a cause for concern because we do not know how much man can modify ocean waters without influencing the marine life which it supports and indirectly the survival of man himself on the planet.

Man's impact on the integrity of water is caused primarily by pollution. The quantity of waste materials reaching the water environment has increased greatly with the increase in size and local density of the human population. As Dr. Squires pointed out this morning, the population problem cannot be divorced from the problem of availability of quality water. Even more important is the explosive increase in technology, which not only increases the amount of pollution, but also is adding unique materials which are not readily recycled by natural processes.

On a global scale, the pollutants of major concern are those which are produced and reach the environment in large quantities, which persist for long periods of time in the environment, and which are toxic to organisms, including man, that depend upon the environment for their existence. There are many other parameters which could be mentioned such as the accumulation of various pollutants within the body tissues, and the transfer of these elements along various parts of the food web or food chain. The pollutants of greatest concern, thus, include various heavy metals, manmade radioisotopes, petroleum hydrocarbons, and persistent synthetic organic chemicals such as the chlorinated hydrocarbons and detergents. All of these have been produced or redistributed by man in unique ways and all of them can now be detected in the waters of the open sea far from shore. For these persistent pollutants, the ocean is the ultimate sink in which they accumulate in the water, in organisms, or in the bottom sediments. They reach the sea by a variety of transport mechanisms. Some are leached or eroded from the land and carried to sea by rivers as solutes or sediments; some are deliberately introduced into rivers or directly into the ocean as domestic and industrial wastes; some are dumped at sea from shipboard or are a direct consequence of ship operations; some are transported by the atmosphere for great distances from the source before being washed out by rain on both land and sea.

Other pollutants may be of great local importance, but are not of great importance in terms of the contamination of the large reservoir of water represented by the oceans. For example, domestic sewage and some agricultural or food processing wastes may be very important locally, not only because they over-fertilize the water and lead to obnoxious growth but also because of possible bacterial and viral contamination. The natural organic compounds in such wastes are soon decomposed in seawater or diluted to insignificant concentrations. In terms of the volumes of seawater, they do not pose critical problems.

In this session the receiving capacity or the assimilative capacity of natural aquatic environments was often mentioned. It has been explained that this concept is no longer acceptable under the Federal Water Pollution Control Act Amendments of 1972 or, as Don Squires said, either there is no assimilative capacity of an environment, or if there is, we do not know what it is.

I would like to point out one aspect of importance that was not mentioned this morning and I would like to take the opportunity to mention it now. This is the time needed for the recovery of an abused system if the insult is removed. The biodegradation of the pollutant is an important contributing process to recovery, but the products of the degradation may remain. The physical turnover time, or flushing of the system is the ultimate mechanism for removal. For pollutants dissolved in the water this can vary from days to centuries, and the ability of the ecosystem to reestablish itself will be subjected to related time constraints.

To give a few examples—rivers and most estuaries have flushing time of days to months. Lake Erie, which was mentioned this morning, has an average flushing time on the order of 60 years, Lake Superior about 250 years; the deep waters of the oceans, centuries to millennia to recirculate. The point that I want to make in this connection is that it is especially dangerous to pollute these large water masses which will take so long to recover.

HEAVY METALS

About a dozen elements are being used or cycled by man at rates which are in excess of the normal geological rates of cycling. A list of these is presented in Table 2. The effects of these in the aquatic environment range from the fertilizing activity of compounds of nitrogen and phosphorus to biologically relatively inert elements such as iron, to highly toxic elements such as mercury. It should be pointed out in connection with this table that the man-induced rates of mobilization of these elements represent his use of the elements and not the rate at which they are being added to the environment. Presumably, a steady state would ultimately be achieved at which time man would only have to mobilize the elements to replace those which become environmental contaminants.

When considering man's contamination of the world oceans the evaluation is more realistically based upon the toxicity of the elements to marine organisms. Table 3 presents a list of toxic heavy metals, listed in order of decreasing toxicity in comparison with the rate at which these are being added to the environment by combustion of fossil fuels. Since the burning of fossil fuel injects these contaminants into the atmosphere, they reach a global distribution rapidly, an effect which is not found if they are cycled more slowly through the land and the freshwater drainage. However, this is only one source of contamination, and these rates of introduction are much less than those shown in the previous table for the same elements.

Table 2.—Man-induced rates of mobilization of materials which exceed geological rates as estimated in annual river discharges to the oceans.

Element	Geological rates[1] (in rivers)	Man-induced rates[2] (mining)
	Thousand metric tons per year	
Iron	25,000	319,000
Nitrogen	8,500	9,800[3]
Manganese	440	1,600
Copper	375	4,460
Zinc	370	3,930
Nickel	300	358
Lead	180	2,330
Phosphorus	180	6,500[3]
Molybdenum	13	57
Silver	5	7
Mercury	3	7
Tin	1.5	166
Antimony	1.3	40

Source: SCEP (1970).
[1] Bowen, 1966.
[2] United Nations, Statistical Yearbook, 1967 data.
[3] Consumption.

Table 3.—Man-induced mobilization by burning of fossil fuels, toxicity to marine organisms, and critical index for various heavy metals.

Element	Mobilization* 10^9g/yr	Toxicity† µg/1	Index 10^{12}l/yr	Rank order
Mercury	1.6	0.1	16,000	1
Cadmium	0.35**	0.2	1,750	2
Silver	0.07	1	70	10a
Nickel	3.7	2	1,350	3
Selenium	0.45	5	90	9
Lead	3.6	10	360	4
Copper	2.1	10	210	7
Chromium	1.5	10	150	8
Arsenic	0.7	10	70	10b
Zinc	7	20	330	6
Manganese	7	20	350	5

*Bertine and Goldberg, 1971 (except for cadmium).
**CEQ, 1972.
†NAS, 1975.

The ratio of the rate of supply from this source divided by the toxicity gives a number which I have called the relative critical index. This index actually represents the volume of seawater which would be raised to toxic levels at the given rate of mobilization by the burning of fossil fuels. For those who like simpler units than 10^{12} liters, I might point out that this unit equals a cubic kilometer, so this is not a trivial matter when you are talking about thousands of cubic kilometers of seawater. The rank order of these elements places mercury, cadmium, nickel, and lead as the four most critical elements, and they are commonly cited as such. In the London Dumping Convention the first two are prohibited, and the others are listed as requiring special care as are arsenic, copper, zinc, beryllium, chromium, and vanadium.

Another way to evaluate the importance of heavy metals as pollutants in the marine environment is to compare their natural concentration in seawater with their toxicity. Data arranged in this way are presented in Table 4. Nickel and mercury are present in seawater at concentrations greater than those which have been judged to be safe on the basis of toxicity. The toxicity values in both of these tables are taken from the "Water Quality Criteria of 1972" prepared for EPA by the National Academy of Sciences. As you know, swordfish have been found to contain mercury in excess of FDA standards. Recent studies by Barber, et al. (1972) show mercury to be equally high in fish preserved for almost a century, so that this contamination should not be attributed to pollution by man. However, it is an example of places where our basic scientific information is inadequate to reach reasonable and sensible regulations concerning some of these pollution problems. According to Table 4, the rank order rates the four most critical elements as being nickel, mercury, cadmium, and zinc.

Table 4.—Toxic heavy metals of importance in marine pollution based on their seawater concentration and toxicity.

Element	Concentration* µg/1	Toxicity† µg/1	Ratios	Rank order
Mercury	0.2	0.1	2	2
Cadmium	0.1	0.2	0.5	3a
Silver	0.3	1	0.3	4a
Nickel	7	2	3.5	1
Selenium	0.45	5	0.09	7
Lead	0.03	10	0.003	9
Copper	3	10	0.3	4b
Chromium	0.6	10	0.06	8
Arsenic	2.6	10	0.26	5
Zinc	10	20	0.5	3b
Manganese	2	20	0.1	6

*Goldberg, et al. 1971, or Riley & Chester, 1971, higher value.
†As in Table 3.

Both of these methods of assessing the critical importance of various heavy metals suffer from inaccuracies in the estimates. However, both show sufficient consistency to justify concern about these metals as pollutants. The toxic level of many of them is so close to the natural concentration in seawater that any unnecessary addition by man should be viewed with the greatest concern. It is obvious that high levels of pollution such as occurred in Minamata Bay in Japan, pose serious problems. This again is an indication that the size and scale of the body of water to which these materials are added have a tremendous influence on the accumulation and the biological effects of these metals.

RADIOISOTOPES

Oceanographers first recognized man's potential for the contamination of the open sea as a result of the atmospheric testing of nuclear explosives. Previously, it had been believed that the oceans were so vast that man's activities would have no measurable effect except in local areas such as estuaries and coastal waters. Atmospheric transport of the fission products of nuclear tests rapidly led to a worldwide distribution and the distribution of these products has been studied extensively as a global experiment, since the materials were added in a relatively short period of time rather than being accumulated over geological eras.

As with all elements, the sea contains natural radioactivity, some of which is derived from the weathering of the earth's crust and some of which originates as a result of the bombardment of the earth's gaseous envelope by cosmic rays. More than 60 of these natural radionuclides have been identified (NAS, 1971).

By December 1968, about 470 nuclear explosions had been detonated in many parts of the world by the nuclear powers (U.S., U.S.S.R., U.K., France, and China). Of these, 113 tests were performed on Coral Islands in the Pacific and 13 over the open ocean. Six tests were performed underwater. Except for the 116 tests which were performed underground and the radioactivity consequently contained, it makes little difference where the test was performed since the mobile atmosphere carries the fission products to all parts of the world.

The radioisotopes distributed throughout the world by nuclear testing include not only the fission products of the nuclear explosion, but also the radioactivity induced in the materials in the structures used or in the earth or water. The fission products which have received the greatest attention to date are ^{137}Cs and ^{90}Sr which have half lives of 30 and 28 years, respectively. Tritium (^{3}H) and the radioisotope of carbon (^{14}C) are present naturally in the environment and are also produced in nuclear explosions (NAS, 1971).

There is no evidence that the fission products added by nuclear testing have produced concentrations of these radioisotopes which are hazardous to marine organisms. Those who saw the experimental area will know that locally it is a different matter. The fact that they are detectable in all surface waters of the world oceans is, in part, evidence of the sensitivity of the analytical methods. As mentioned above, their presence in seawater provides a unique identifying "tag" of water masses and this has permitted critical analysis of some of the circulation patterns of the waters of the deep sea.

PETROLEUM

Another global pollutant which is of increasing importance and concern is petroleum. Petroleum is a complex natural mixture of a large number of hydrocarbons. Petroleum has accumulated over millions of years, but we are now exploiting this resource at a rate vastly in excess of the rate at which it can be replenished.

Natural seeps of oil have probably occurred throughout geological history. As a result of our rapid use of this material, however, the rate of pollution of the sea by oil has been greatly increased. In 1971 the world consumption of oil approached 2,400 million metric tons. Because most of the oil is used in parts of the world other than the production areas, more than half of this oil has been transported by sea in either the crude or refined form (NAS, 1975).

It is inevitable that oil pollution of the oceans will increase as a result of this great use and transportation of petroleum. Various estimates have been made of the rate of addition of oil to the oceans, and the latest of these is shown in Table 5 (NAS, 1975). This pollution is at the rate of six million metric tons per annum (mta). Although accidental spills such as the grounding of the Torrey Canyon or the Santa Barbara oil well blowout are spectacular events and attract the most public attention, they actually account for only about 5 percent of the marine pollution by oil. Transportation losses account for about 30 percent of the total and a similar quantity is provided by urban and river runoff.

Oil slicks and tar balls have been observed on the high seas in considerable quantities (Horn, et al. 1970; Morris, 1971). Beaches throughout the world are coated with tar in areas near the main transportation routes even when no accidental spill has

Table 5.—Petroleum hydrocarbons introduced into the oceans.

Source	Input mta	Percent
Natural seeps	0.6	9.8
Offshore production	0.08	1.3
Transportation		
Tanker operations	1.33	21.8
Other ship operations	0.5	8.2
Accidental spills	0.3	4.9
Coastal refineries	0.2	3.3
Municipal and industrial wastes	0.6	9.8
Urban runoff	0.3	4.9
River runoff	1.6	26.2
Atmospheric input	0.6	9.8
Total	6.11	100

Source: NAS, 1975.

occurred nearby. This tar is the end product of the weathering of the oil reaching the sea. It is mostly an aesthetic degradation of the environment.

Although the direct toxic effect of oil on marine organisms is somewhat controversial, the evidence is clear that all oils contain toxic substances, though in different proportions. The impact is largely dependent upon the type of oil and the degree of exposure of the organisms to the oil before it disperses, evaporates, or decomposes. There is good evidence (Blumer and Sass, 1972) that in relatively shallow coastal waters the oil can become incorporated in the sediments where it can persist for long periods of time. After all, this is the way oil is formed in the first place in marine sediments under anerobic or anoxic conditions. The oil sequestered in the sediments of shallow waters can be released at random intervals from the sediments to the water as a result of storms, with another sequence of biological effects taking place.

The pollution of the high seas by oil has become an international problem because of the increase in oil tanker traffic and ships burning fuel oil. The Intergovernmental Maritime Consultative Organization (IMCO), a specialized agency of the United Nations, has held a series of international conferences which have drawn up and subsequently modified the "International Convention for the Prevention of Pollution of the Sea by Oil." The most recent International Conference on Marine Pollution was held in London in October and November 1973 (IMCO, 1974). The draft convention provides regulations for the prevention of pollution by oil, by noxious liquid substances in bulk, by harmful substances in packaged form, and by sewage and garbage from ships. When the provisions of the Convention come into full force and take effect, the pollution of the sea by oil resulting from transportation losses will be greatly reduced. As Table 5 shows, however, this will still leave considerable oil pollution so long as our technology depends so heavily upon this energy source.

SYNTHETIC ORGANIC COMPOUNDS

A wide variety of synthetic organic chemicals is also reaching the environment. The production of synthetic organic chemicals in the United States in 1969 was 135,000 million pounds, a 12 percent increase over 1968. This quantity is not an insignificant fraction of the natural productivity of the sea (NAS, 1972). Although many synthetic organic chemicals are readily degradable to elementary materials which re-enter the chemical cycles in the biosphere, the more stable compounds that enter the environment, whether as waste materials or through their use, are of concern. Particularly critical are those compounds which are not found naturally, since organisms capable of decomposing them have not evolved and they may persist for long times and accumulate in the biosphere.

The chlorinated hydrocarbons such as DDT and its decomposition products and polychlorinated biphenyls (PCBs) are of particular concern since they are not readily biodegradable and the ocean is the ultimate sink for these compounds. Harvey, et al. (1972) found substantial concentrations of DDT and its breakdown product DDE and even higher levels of PCBs in a variety of organisms collected from the open sea many miles from land. Their results confirm the probability of atmospheric transport since the distributions show no clear-cut gradients which would be expected with river transport. Being oil soluble, these compounds are concentrated in the lipid pool of the organism with a maximum concentration of 3,300 micrograms/kg for DDT and DDE and 21,000 micrograms/kg lipid for PCBs.

Woodwell and his associates, who will be speaking to us tomorrow but perhaps not on this subject, modeled the circulation of DDT in the biosphere and concluded that the largest reservoir is in the atmosphere, but also that the amount not decomposed by ultraviolet rays in the troposphere will ultimately be added to the surface of the sea (Woodwell, et al. 1971). The concentrations observed by Harvey, et al. (1972) were not as great as those assumed by Woodwell, et al. (1971) for oceanic fish or plankton. The lower accumulations in marine organisms could be caused by a shorter atmospheric half life of the DDT than assumed by Woodwell and his associates, by a faster degradation in the marine environment, or by greater accumulation in sediments than those estimates used in the model. Again, we emphasize the lack of hard, useful scientific information to evaluate this problem. Clearly, additional research is needed to evaluate the persistence of these compounds in the environment.

A variety of other synthetic organic chemicals, including other pesticides, detergents, and pharmaceuticals are also undoubtedly reaching the marine environment but with impacts that are virtually unknown. It has been estimated that about 60 percent of the phosphorus content of sewage effluents in some developed countries is caused by the extensive use of high phosphorus-containing detergents. Like other substances contained in sewage, the impact is largely local where substantial modifications to the biota can be caused by the processes known as eutrophication.

CONCLUSIONS

I found it difficult to write this paper without proceeding to the biological concerns since I am an ecologist. Since I was told to talk primarily on the chemistry of this problem I have restrained myself, to some extent. I would like to point out that, as was mentioned this morning, very critical problems are caused by mixed pollutants and when you look at the environment as a receiver of a set of pollutants you have to think of the total picture. The synergism or the antagonism among different pollutants is of critical concern. I think that this subject is under discussion and consideration at this symposium.

Man's technology has not yet destroyed the ability of the oceans to support marine life which provides a valuable food resource for many nations throughout the world. However, the earlier optimism of the oceanographer that the seas are so vast that the impact of pollution in the open sea would be undetectable has been proven false. In inshore and coastal waters, the value of the sea for many of man's desired activities has been decreased by marine pollution.

The optimistic part of the picture is that we are now recognizing the importance of pollution in general, and active steps are being taken to control pollution and ameliorate the impact. Hopefully, it is not too late and we can maintain the quality of our aquatic environment and restore those environments which we have seriously damaged. Appropriate actions taken by the Environmental Protection Agency in the United States, by similar organizations in other countries, and by international agreement can help to maintain or restore the integrity of water, both fresh and marine, throughout the world. This is an enormous responsibility on the part of our friends in the Environmental Protection Agency. I hope that a conference such as this is of some help to them. In any case, they have my hearty support in what they are trying to do.

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DISCUSSION

Comment: Since many of the synthetic organic chemicals are toxic in nature and so many of them are also accumulating in the environment, what do you feel about the role of predictive toxicology and the control of the manufacture and dispersal of these things?

Dr. Ketchum: What can one say except that I'm all for it. There certainly should be screening tests for any substance that is being produced in large amounts, as any profitable substance will be. The screening should be made early in the development of the product in order to evaluate what impact its production, the whole manufacturing process, the whole waste material produced will have upon the environment.

This is done only for drugs in this country at the present time. It should be done, in my opinion, for all organic substances and pharmaceuticals. Some screening mechanism should be required, which is not going to be easy I admit, but at least it should be a part of the normal development process of any material.

Comment: I'd like to ask, Doctor, about the disappearance off Peru of the fish menhaden, a few years ago. Was pollution a factor in this?

Dr. Ketchum: The anchoveta was the fish. So far as I know, pollution was not a cause of its disappearance. This is a phenomenon that goes back historically for many years. Periodically, there's a shift in the ocean currents and this displaces the population. The Peruvian coast is an area of natural upwelling which leads to very heavy productivity, very heavy growths, and this supports an enormous population of anchoveta.

This fishery reached a level of two billion pounds just prior to this change and it dropped to less than a tenth of that the next year, but the fishery had become so efficient that they continued to fish this population in a way that had never happened before. Previously, when the fish disappeared as a result of the change in ocean currents, the fishermen just gave up and went home and took a rest. This time they didn't. They used echo sounders and everything else. They continued to fish actively and further depleted the population. I haven't seen the last year's figures, and whether the fishery will come back or not is a guess. I couldn't predict. The basic, primary productivity that supported this enormous fishery will undoubtedly come back because phytoplankton are ubiquitous and they're everywhere in the water, but the anchoveta was a localized fishery. Whether there's enough left to reproduce the population, I think only time will tell.

But that's one thing that we don't want to blame on pollution. That's nature. Nature has had catastrophes throughout geological time and will continue to have catastrophes. There's just no reason in my mind why man has to be another catastrophe.

Chairman Ballinger: Dr. Ketchum, I have a question. There was a comment relating to the ocean disposal suggesting that we simply go farther out into the ocean. As an oceanographer, are our physical modeling techniques sufficiently reliable so that we can make any kind of predictive activities relating to such discharges?

Dr. Ketchum: I don't want to say we know nothing about it because we know something about it. There have been recent studies on the rate of biological degradation of dumped sewage sludge which indicate that it is faster than had been anticipated. It is clear that the amount of material that has been dumped over the last 40 or 50 years would produce a tremendous mound in the area if it weren't being decomposed and dissipated. Mounds have been found and mapped for the dredge spoil and building rubble that have been dumped in the New York Bight, so it is not a lack of prior historical records or the lack of present ability to map accumulations. In the sewage sludge dumping area, there is a record of accumulation a meter in depth from one core, but an adjacent sediment core taken as soon thereafter as possible found virtually nothing.

As far as the currents are concerned, I think we understand the current regime in that area adequately, but currents alone don't tell you where some material denser than seawater is going to go and is going to end up.

Moving the dump site to a new area will not solve the problem. I think, as was mentioned this morning, that the logical thing to do with any of these waste materials is to develop the technology to recycle them. The sewage sludge has a lot of useful fertilizing chemicals and organic material which could be used as soil conditioners and as fertilizers and thus made of value. Unfortunately, the early history of our sanitary engineering profession called for the cheapest possible system, perhaps. Combining urban or storm runoff with sewage aggravates the problem. Allowing industries to put their untreated waste directly into the sewage collecting system makes things worse. Consequently, this sludge being dumped has high levels of hydrocarbons, of pesticides, of several toxic heavy metals. I suspect if you took the sludge, dried it, and put it on your garden you would successfully kill almost any plant that grows there.

It's obvious that sludge disposal is killing organisms in the marine environment. But a lot of the suggestions for alternative methods of disposal will move this impact on the environment from one place to another, and will not necessarily be a solution.

I think a solution can be found for sewage sludge disposal and I'm heartily in favor of finding a solution for it. As near as I can tell, if you're going to destroy some 20 square miles of the earth's surface it may be just as well to put the sludge in the ocean as it would be to put it in a great big pile in the center of Manhattan Island and see what you could destroy there.

It's a tough problem.

Comment: In the water quality standard setting process, is the philosophy of no discharge based upon predicted toxicology scientifically and legally defensible?

Dr. Ketchum: I have only one way to insure "no discharge" of the wastes of the human population and of human technology and that is to destroy *Homo sapiens.* I'm not at all sure that zero discharge is achievable so long as we have human beings on earth. Throughout geological time, man probably created no larger perturbation on the environment than any other large voracious carnivore. This is no longer true. We could go back to the hunting stage of carnivores, when we would require something like 10 square miles per individual for maintenance, food and subsistence. This would limit the world population to something like four million people instead of four billion people, which it is today.

So long as we have four billion people on earth, so long as we heat houses and like to be warm and comfortable, so long as we have to eat, man's existence on earth is going to have an environmental impact.

I think it is possible to achieve a considerable improvement without going all the way and revert man to a hunter in the open field.

THE CHEMICAL INTEGRITY OF SURFACE WATER

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In my view, a presentation on the chemical integrity of surface water can deal either with criteria (or standards) of surface water quality or the means of achieving them. From the earlier discussions and the titles of those that will follow, it seems clear that the emphasis here should be on the former, the factors of water quality.

Coming from a health agency that is concerned primarily with public water supplies, it is appropriate for me to use criteria of drinking water quality as my model, although I intend my remarks to be more broadly applicable.

From a chemical point of view our concerns are directed to four major groups of constituents that can impair water quality. Not in order of importance, because that will vary with local conditions including land use, wastewater discharge, and beneficial uses, these groups are: total dissolved minerals; inorganics, of which the most significant may be toxic metals; organics, either clearly defined such as the pesticides, or a broad spectrum of unknown substances naturally occurring in water or added as a result of man's activities; and, lastly, dissolved gases. In a health context these constituents can be separated into those that exert an adverse health effect, that is, are or may be toxic, and those having an undesirable effect more oriented to aesthetics or consumer acceptability. In the broader context of environmental protection or enhancement, the criteria will differ more quantitatively than qualitatively, although special concern must be given to those chemical constituents, especially nitrogen and phosphorus, that stimulate the growth of undesirable organisms or undesirable numbers of organisms.

The principal sources of information regarding criteria and standards that may be derived from them are the "blue book," "Water Quality Criteria 1972," a report prepared for the Environmental Protection Agency by the National Academies of Sciences and Engineering, and the Drinking Water Standards issued last in 1962 by the Public Health Service and now under revision by EPA. A number of speakers in this symposium have been important contributors to the blue book; I hope they will not object to my use of the fruit of their labors.

TOTAL DISSOLVED SOLIDS

Total dissolved solids or filtrable residue are discussed in the blue book but a recommended upper limit is not given. At high concentrations a physiological effect can be obtained but since the effect is a function of specific ions, control can be imposed by setting limits for those ions. In an agricultural application, total dissolved solids or, more specifically, salinity, can be critical because there are numerous crops with low salinity tolerances. The Colorado River exemplifies a situation in which increases in salinity resulting from irrigation return flows make for an unusable end product downstream. Control by modification of agricultural practices or actual desalination of the river water is necessary to protect beneficial uses.

Water pH can be included under this general category of dissolved minerals. Although no standards exist or are proposed, it is clear that the optimum pH is around neutrality, say the range from 6.5 to 8.5.

Biologically, a critical aspect of both total dissolved solids and pH is the stability of the level, that is, there may be adverse biological impacts of marked and rapid fluctuations in either. Such changes may result from waste discharges and in the case of pH, from the massive growth of algae that produce an elevated pH, at least during the daylight hours of active photosynthesis.

INORGANICS

Table 1 shows the proposed drinking water standards for inorganic constituents that represent a health hazard. At some later date standards less related to health and more to aesthetics will be added. This list will undoubtedly include all or most of the other 13 inorganic constituents discussed in the blue book (alkalinity, ammonia, boron, chloride, copper, hardness, iron, manganese, phosphate, sodium, sulfate, uranium, and zinc). The blue book sections on fresh and saltwater life add such metals as aluminum, antimony, beryllium, molybdenum, nickel, phosphorus, thallium, and vanadium and the halogens bromine and chlorine. Quantitatively, the maximum concentrations suitable for human exposure are similar to those for other organisms. Notable exceptions are ammonia, which may be added to water in waste discharges and is toxic to fish (recommended limit in fresh water is 0.02 mg/l); mercury, for which the freshwater limit is 0.05 μg/l; and zinc (saltwater limit is 0.1 μg/l). To meet the recommended limits for these constituents will require essentially total oxidation or removal of ammonia, the principal nitrogen compound in domestic wastewater, and removal of mercury.

Table 1.—Maximum contaminant levels for inorganic chemicals.*

Contaminant	Level mg/l
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Cyanide	0.2
Fluoride	1.1 to 1.8 (depending on ambient temperature)
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.
Selenium	0.01
Silver	0.05

*Source: Proposed Interim Primary Drinking Water Standards, EPA

An interesting and important conflict between human needs and general environmental protection is demonstrated in the case of copper and the halogens. Copper salts are used frequently to control nuisance algae in water supply reservoirs. Although high concentrations of copper are toxic to man, the concentrations used for algae control seldom exceed 1 mg/l and do not pose a threat. Fish, on the other hand, may be killed by exposures as low as 0.05 mg/l. Until suitable substitutes for copper are developed, a difficult balance must be negotiated between copper concentrations high enough to kill algae which contribute to aesthetic degradation of drinking water by producing tastes and odors and also increase the cost of water treatment, and protection of fish in our reservoirs.

The case of the halogens is more acute. Chlorine, our most commonly used disinfectant for protection of recreational users of water and production of shellfish free from human enteric organisms, is toxic to fish at such a low concentration as to challenge our capability of measuring it. While it is not yet established that the major toxicant is chlorine itself or the chlorinated products produced in the treated waste, fish toxicity results from conventional wastewater disinfection. Initially the choice may be between human health protection and environmental preservation. As a representative of a health agency, I can argue only for the former. From a longer term point of view, alternatives to the usual disinfection must be considered. This may be by introduction of the added cost of dechlorination or by the use of disinfectants such as ozone or others yet to be investigated.

With the exceptions noted, I would generalize that surface water that is safe and aesthetically acceptable for human use will be safe for the environment. What I have talked about up to now has been relevant to biological toxicants. Of little direct public health concern but of tremendous environmental significance is the subject of biological stimulants. I refer, of course, to nitrogen, phosphorus, and a poorly defined array of nutritive substances present in treated wastewaters. These may have immediate impact on the growth of algae and other aquatic plants to such an extent that there is interference with wildlife and recreation and may lead to general environmental degradation. Solution of the problem seems obvious; if nitrogen and/or phosphorus are key elements that may define biological activity in a surface water, their removal from wastes discharged to that water will prevent nuisance eutrophication. Unfortunately, these elements are important inorganic constituents of wastewater, especially domestic wastes; the levels at which biological responses occur are very low; and assured removal is not always possible but always expensive. Additionally, it must be remembered that wastewater does not represent the sole source of these elements.

Broad environmental management, including land use planning and air pollution control, are critically required. Lake Tahoe provides a useful example. It is an alpine lake that has been described as nitrogen-sensitive on the basis of extensive biosassay experiments. Increased population pressures on the lake basin and the desire to preserve the natural beauty of the lake have led to the decision that wastes generated in the basin should not be added to the lake but removed from the basin. This is being done with wastewaters, but also important are solid wastes, home use of fertilizers, air pollutants that are carried down by precipitation, and general land development. Only a totally integrated effort can preserve indefinitely those attributes of Lake Tahoe which make it deservedly famous.

ORGANICS

Table 2 shows the proposed limits for organics in drinking water. In an environmental sense the list is incomplete since it does not include common contaminants of other than potable waters such as oil and grease, phthalate esters, and polychlorinated biphenyls (PCBs). These may be added to water through waste discharges or other human activities. In the sense of defining criteria, the case against oils is simplest and although numerical representation of the criterion is difficult or impossible, the requirement that visible surface oils be absent usually suffices. To protect freshwater organisms, the blue book recommended levels for phthalates and PCBs are 0.3 and 0.002 μg/1, respectively.

Table 2.—Maximum contaminant levels for organic chemicals.*

Contaminant	Level, μg/1
Carbon chloroform extract	700.
Chlorinated hydrocarbons	
Chlordane	3.
Endrin	0.2
Heptachlor	0.1
Heptachlor epoxide	0.1
Lindane	4.
Methoxychlor	100.
Toxaphene	5.
Chlorophenoxys:	
2, 4 - D	100.
2, 4, 5 - TP Silvex	10.

*Source: Proposed Interim Primary Drinking Water Standards, EPA

A serious deficiency in both criteria and standards exists in that the number of organics potentially present in water is almost unlimited and yet we use a crude catchall category, the carbon chloroform extract, to define our concern. If, for example, a single organic with a toxicity level equal to that of heptachlor were present, a concentration of 700 μg/1 or 7,000 times the heptachlor maximum, would appear to be acceptable. Clearly, chemical tests for toxic organic compounds are inadequate. More pertinent to the protection of human health would be rapid and meaningful bioassay tests comparable to those used for the protection of aquatic organisms. Serious efforts to develop such tests are needed urgently.

Of special note is the current clamor for the use of renovated wastewater for domestic purposes. While highly treated wastes may meet existing or proposed standards, the absence of knowledge of specific organic compounds present and their human health effects, and the observation that carcinogenic substances have been identified in wastewaters or receiving streams, suggests strongly that the standards are inadequate for such circumstances. To protect the public health such renovated wastes should not be used as a source of domestic supply until or unless more information is obtained. The blue book includes a list of about 100 organic compounds of which the toxicity to marine organisms has been studied. No comparable data for humans exist.

DISSOLVED GASES

No drinking water standard for dissolved oxygen has been proposed, but the blue book does recommend a level near saturation. Since oxygen is a critical requirement for most water forms and waste discharges usually exert an oxygen demand that results in receiving water oxygen depletion, fish and wildlife protection can be provided by meeting the criterion. Fish protection also requires that water not be supersaturated and specifies that the total gas pressure should not exceed 110 percent of atmospheric pressure. The single toxic gas of concern is hydrogen sulfide which will affect fish at a concentration as low as 0.002 mg/1. Usually the presence of an adequate supply of dissolved oxygen will guarantee the absence of hydrogen sulfide so that both odor nuisance and fish protection will be afforded by oxygen.

SUMMARY AND CONCLUSIONS

I have made reference to the principal chemical factors affecting water quality. In the context of toxic substances, meeting the drinking water standards generally will protect aquatic biota. Since the standards do not include biostimulatory factors these must be added for the protection of the environment. Wastewater treatment alone may not be able to provide for total protection so that we must consider management of the total environment, including water resource management, as a necessary condition for restoring and maintaining the chemical integrity of our waters.

In the short term, wastewater treatment and disposal must be oriented to protect the public health. As technology and funds become available the same concerns for the whole environment should be manifested.

DISCUSSION

Comment: If you were to choose the Drinking Water Standards as your model, I think you would find that the water quality criteria, for example, for the chlorinated hydrocarbon pesticides are much lower when you consider fish toxicity; it so happens that fish are much more sensitive to the chlorinated hydrocarbons, so in this case I would recommend that one should look at both effects, the health effects in humans and the effects in fish and maybe choose a lower number, but I think that it would be a mistake, especially in the case of pesticides, to choose the much higher numbers as to the health aspect in humans.

Mr. Greenberg: I think that what you're saying is absolutely correct, namely, that from a quantitative point of view the Drinking Water Standards may not be appropriate. I myself cited three examples: ammonia, mercury, and zinc. Here, as with the pesticides, the number, that is, the concentration that is specified for human exposure may be too high for fish or other organisms inhabiting a water environment.

I don't think that invalidates the model, the Drinking Water Standards. It simply indicates that we have to adjust the numbers. I'm in complete accord with that.

Comment: I think you kind of slid over a problem which I would guess that in your capacity you're well aware of and that is the laboratory problem. Do you see in the next 2 years sufficient advance in the laboratory state-of-the-art to allow routine monitoring of some of these parameters at the low levels that you mentioned; for example, I heard you say something about a 0.05 part per million mercury standard. To my knowledge that's not a level which you can measure routinely in the laboratory.

Mr. Greenberg: I think the question is a most appropriate one and really very appropriately put to the two of us who are standing or sitting now on the podium.

Dwight Ballinger, as you know, is very much involved with the development of laboratory methodology for EPA and I have similar responsibilities both in the State of California and with Standard Methods.

I'm in a very awkward situation in responding to that question in the sense that I start by accepting that which the biologist tells me should be the level of concern. If I am told that 0.05 mg/l is the level of concern for the aquatic biota, let's say for mercury as you used the example, then I'd first ask, how was it measured?

How do you know that you're really talking about 0.05 mg/l and not 0.005 or 0.0005 or even 50 mg/l.

I'm sure that gross separation can be made, but some of the more refined measurements may in fact be beyond what is conventionally possible.

That's one area of my concern and relative embarrassment. The other deals with the fact that I make my living from laboratory type activities and so I should insist on everybody measuring everything all the time because that's going to be good for me and people like me. On the other hand, I recognize that this is not a socially desirable way to spend our money so that, again, we have to negotiate a balance between what we might do and what it is reasonable for us to do.

I heard this morning very negative comments with respect to cost benefit analyses. It seems to me that we have to have an awareness of cost benefits in terms of how many samples to take and how many analyses to make.

The real issue is how much we are technically able to detect. If we talk about pesticides, I think that with the development of gas chromatographic techniques and with the coupling of gas chromatography and mass spectroscopy it is really possible to identify almost anything, given time and money enough.

On the other hand, for some of the inorganic constituents, we may have techniques but they're not nearly as widely used.

Atomic absorption spectrometry is very good. With the heated graphite atomizer the sensitivity can be improved still further. Other analytical procedures, such as x-ray or neutron activation, are probably beyond the scope and the financial possibility of most laboratories engaged in water or wastewater analysis.

I can talk a long time on the question, but I really can't give you an answer. I think it might be useful to ask our moderator to make some comments on this.

Chairman Ballinger: Thank you. I don't have any better answer either. However, I think there are a couple of points that we need to look at. One is the question of the setting of standards for the protection of the integrity of the environment. The question arises whether the standards should be set on the best information we have concerning an acceptable level of a given pollutant, based on probably toxicological data, or should the standard be set on what our present technology allows us to measure.

I raised this question many, many years ago when I was a very green young chemist with Dr. Stockinger, whom I think many of you will recognize as one of the Nation's foremost toxicologists. He said we will always set the standard on the best information we have as to the effect of a material and then we will challenge the analytical chemist to meet that standard. I think we are and should be in that mode.

Secondly, I should point out that our analytical technology is advancing very rapidly. We are now measuring things at concentrations that we could not measure as recently as 2 or 3 years ago. Therefore, I think we as analysts should always have the challenge before us to meet the standard, that is, to match our technology to the problem rather than settle for the status quo.

We need a challenge and I think we are meeting those challenges. I'm concerned that we not use limitations of analytical technology as a reason for not setting the most reliable criteria to protect the environment.

Comment: When you're doing this, aren't you setting unenforceable criteria? If you cannot monitor an industry, these criteria that you have, and your people who go out to the industry or the stream or whatever, aren't you setting unenforceable criteria?

Chairman Ballinger: They may be unenforceable at the moment; I don't think they'll be unenforceable very long.

We're dealing with a dynamic technology and I would prefer to say that, temporarily at least, we may have to report a number which is not as far down as we would like, but I think that's still preferable to setting a standard and then turning around this time next year and going out to the public and reducing the standard by a factor of 10 because we have increased our technology.

Comment: Don't you leave yourself open to legal action which could knock out your criteria and put them back to a limit that could be monitored? Couldn't you be taken to court when you say that you cannot enforce this criteria because we cannot measure it? Presumably you'd be forced by the court to go to a monitorable criteria.

Chairman Ballinger: We will monitor and take legal action to the best of our technical ability at any time. We will also stipulate that in the enforcement of all of the standards the analytical capabilities of the present technology will be taken into consideration in the preparation of the case.

Mr. Greenberg: I think this question has raised a very interesting one; which came first, the chicken or the egg? Dwight's reply was in the context of the regulatory agency setting standards which are based on good criteria and good goals but may not be reachable in terms of analytical capability.

On the other hand, Dwight, as a regulatory agency representative, is also responsible for defining the analytical methods which may be used. EPA has listed 73 specific substances to be measured and has defined specifically, by page number, the sources for those analytical techniques.

Both things now, the standard and the analytical technique are in the Federal Register and both have regulatory status. To say that the analytical techniques would keep up with the regulatory activities, without requiring an annual or a more frequent change in the regulations is really not quite true because you still have to change the regulations for the laboratory methodology. You will always be jumping in some kind of a leapfrog situation. I don't think you can beat that system, though.

Chairman Ballinger: From a pragmatic standpoint, we find it a lot easier to change the analytical method than to change the standards.

Mr. Greenberg: I'm sure.

Comment: On that point, do you feel that the current practices in making legitimate or making generally acceptable a given new laboratory procedure are adequate? Does the cycle for revision of Standard Methods or EPA methods, respond rapidly to the advances in the state-of-the-art so as to allow a timely utilization of these new methods as they become available?

Chairman Ballinger: In terms of EPA, for example, we do have an annual revision of Section 304(g) which is the test procedures methodology for the pollutant elimination discharge. Thus, there is an annual cycle so that not longer than 1 year would pass without our making a revision.

In the case of EPA, we can begin, at least in our own laboratories, by the adoption of an analytical method at any time it is ready. It will be then officially promulgated within 1 year of that time.

I think that's as sure as we ought to be. It is unlikely that we can develop a method, refine it, adequately test it, publish it as proposed, and then final, in anything less than a year. I don't know that we want any greater turnover time than that, but I think it is adequate to keep up with the technology as far as EPA is concerned. I'm going to let Mr. Greenberg talk about Standard Methods.

Mr. Greenberg: I think that most people who use Standard Methods and who see the publication dates of the book may tend to be misled by the fact that in the last couple of decades the publication cycle has been at roughly 5-year intervals. I mean "misled" in the sense of thinking that unless it is within the hard covers of the book, "Standard Methods for the Examination of Water and Wastewater," it is not an approved method by the three societies which sponsor the production of that book.

The societies, some 10 years ago, adopted a technique of having a review of procedures presented to the Joint Editorial Board in published form, more or less the kind of thing that Mr. Ballinger just referred to, having that approved and published in the journal or journals of the society and becoming a standard method.

We are hoping that subsequent to the edition which is now in preparation, the 14th Edition, which should be out towards the latter part of this year, that the cycle of the actual hard cover book will be every 2 years. We're aware of the concern for keeping up and we're doing whatever we're able to do to keep up.

Comment: Can you give me a rough figure of the current annual expenditure in monitoring a typical water supply in this country?

Secondly, by what factor does this great expenditure need to be increased to satisfy his recommendations?

Mr. Greenberg: I really have no dollar figures on this. I know that in California we have some 470 laboratories which are approved by the Department of Health for making water analyses.

I know that if the requirements of EPA are met, either in terms of waste discharge monitoring or drinking water supply monitoring, or both, the number of laboratories or the size of laboratories in California is probably inadequate to handle the demand. This comes back to that item of concern which I expressed earlier about how much money should we spend on monitoring.

I think it's a very difficult thing to do and although I have not attempted it, I am convinced that it's necessary for a balance to be defined between the protection afforded by additional monitoring and the costs which the additional monitoring require.

Comment: We've spoken about the deficiencies of laboratory technique, but I think there's a problem area as far as sampling is concerned. To mention a couple of cases: we are in the process of developing criteria for oxygen and hydrogen sulfide as they relate to protecting a beneficial use, in this case, aquatic life. These oxygen and hydrogen sulfide requirements are to be measured in the waters and sediments.

I'm just wondering if we asked the States to adopt these as water quality standards how are we going to measure these constituents of the sediment? In situ, maybe, or possibly by going down and digging up the appropriate samples. How do we do this?

Are we doing any work in this respect?

Chairman Ballinger: I don't know of any work that is specifically addressed to the measurement of dissolved gases in sediments.

My initial impression is that these would have to be measured in situ, that the transport of that kind of sample would certainly degrade it.

Mr. Greenberg: I think that question, though, can be looked at from a much broader point of view.

We have commented already on potential inadequacies in terms of laboratory methodology.

Likewise, we have potential inadequacies of sampling. We also, and this is really the critical thing, have to have some idea of inadequacies in terms of the establishment of the criteria. To get back to the 0.05 mg/l of mercury, how well fixed is that number, because enforcement or control really hinges on that number and other numbers like it.

If the criteria and the standards are based on numbers with huge error factors built into them, and certainly many of the biological tests do have large error factors in them, then the ultimate of refinement of sampling and laboratory techniques is really irrelevant. We're just barking up the wrong tree if we're focusing back on a criterion which is really meaningless.

Comment: I'm a consulting engineer in private practice here in Washington. In the analogous situation for enforcement of the proposed new standards you have the conditions of air pollution and solid wastes.

In private industry we find that the regulatory agency charged by law with enforcement is quite severe in the private sector. Yet when they encounter the comparable situation in the Federal or State sector the answer is ah, fine, idealistically we'd like to do it, but constraints of our budget do not permit this and we permit tolerance, we permit waivers, we permit non-enforcement on Federal installations, including military installations, specifically in the field of solid waste, also hostile and hazardous waste, and air pollution where someone is locked in for a long term, closed contract, yet emissions admittedly fail to meet State and Federal standards.

What assurance do we have these standards coming forth now are going to be as uniformly enforced at the State and Federal levels as they are in private industry?

Mr. Greenberg: I certainly can give you no such assurance. I know, for example, in California that only recently have we been able to do anything in terms of standard setting or criteria or enforcement, if you will, against Federal agencies, but not including the Department of Defense. I cannot speak for even California to give you that kind of assurance and I don't know whether Mr. Ballinger or anyone else could give you that assurance on a National level.

Chairman Ballinger: Very, very fortunately I am not a part of the Office of Enforcement and General Counsel.

Comment: I can make a comment on that. I think part of it is on the way to legislation which is coming around to taking care of this. For example, the Federal Insecticide, Fungicide and Rodenticide Act has come out recently. Applicators of the regulated insecticides and so on have to meet safe criteria before they can operate on Federal installations. Thus, the State is going to have a hand in this and I think that the legislation is worded just right; all Federal agencies will have to come into it.

Mr. Greenberg: I think another example is in the context of the Occupational Safety and Health Administration. I'm not sure on a Federal level, but OSHA requirements are equally applicable to State and local governmental institutions and private institutions.

The one difference in terms of dealing with the private sector and the public sector in the OSHA context is that the public institutions are not subject to fines, as are private institutions.

THE INTEGRITY OF GROUND WATER

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GROUND WATER—FACT AND FICTION

Contrary to popular belief, ground water is neither mysterious nor occult; it does not occur in underground lakes, rivers or veins, and spring water is not synonymous with purity. These are but a few of the common misconceptions concerning ground water. Since some misconceptions of ground water are widely held, they are first examined before proceeding with a description of ground water behavior and attributes.

Misconception: Ground water occurs in underground lakes, rivers and veins.
Fact: Generally bodies of ground water bear no resemblance to surface water bodies.

In the vast majority of cases, ground water occurs in rock formations that have a sufficient number of interconnected openings (permeable material) for the water to pass through them. Not uncommonly, these aquifers (water-bearing rocks) are connected for hundreds or even thousands of square miles. Along many river valleys, the floodplain deposits consist of permeable sand and gravel. In cases such as these, the ground water commonly flows in the same direction as the surface stream and there may be a concentrated underground flow adjacent to the stream that is different from the underground flow in nearby areas. This does not mean that the ground water flowing in the stream-side deposits is in any manner similar to water in a surface stream. During the last Ice Age, when glaciers advanced across the northern part of the United States, many of the pre-existing stream channels in these areas were filled and the streams were forced to develop other courses. Many of these now-buried river valleys contain vast quantities of ground water, but the enclosed water must not be likened to an underground river. This erroneous concept, however, is based on fact, because in areas where limestone forms the major aquifers, the water may slowly flow in large underground openings such as caves and solution channels. In one sense these large openings are similar to underground rivers and lakes.

Misconception: Ground water is mysterious and occult.
Fact: Natural laws control the occurrence and movement of ground water and therefore it is predictable.

In past centuries, before the development of scientific techniques of ground water hydrology, the natural laws controlling water movement were unknown. This led to the concept, preserved in case law, that the occurrence and movement of water in the ground is mysterious and occult—i.e., that the principles of its behavior cannot be known. In fact, using well-established natural laws, the quantity and quality of ground water are predictable both in space and in time.

Misconception: Water rushes so rapidly underground that its presence can be detected by listening for the noise.
Fact: In most cases ground water flows only a few tens of feet per year.

Some people believe they can detect the presence of large quantities of water underground merely by placing their ear to the earth and listening for the rushing water. This is not possible because ground water moves very slowly through the earth. In fact, in most cases it moves only a few feet per year. Locally, however, it may flow very rapidly in limestone terrain characterized by large openings such as caves. Ground water velocity is of particular importance in water pollution problems. Due to its slow rate of movement, an area once contaminated may remain unusable for years. It is primarily for this reason that disposal of wastes on and in the ground must be closely regulated.

Misconception: Ground water, when removed from the earth, is never returned.
Fact: Ground water is a renewable resource.

In most parts of the country ground water, when removed from the ground, is constantly replaced. Thus, ground water is a renewable resource. Water is constantly seeping into the ground and is continually discharging into streams, lakes, and wells. Areas where water seeps into the ground are called recharge areas; this includes virtually the entire land surface. Some types of soil, however, will accept water much more rapidly than others. For example, the rate of infiltration (the rate at which water seeps into the ground) through sandy soil will be much greater than through a heavy clay soil. Because of this phenomenon relatively high rates of recharge (infiltration) occur along river flood plains and in sandy or gravelly areas. Areas with high rates of recharge must be carefully managed for two major reasons. First, they provide water to underlying groundwater reservoirs (aquifers) and, secondly, water-soluble waste products stored in these areas will also infiltrate and contaminate the underground supply. Consequently, areas of high recharge must be protected in order to maintain the quantity of water in storage and to protect its quality.

Misconception: Ground water migrates thousands of miles through the earth.
Fact: Most ground water withdrawn is replaced in the near vicinity.

Much of the water in a groundwater reservoir infiltrates within a radius of a few tens of miles of where it is found. It has not traveled in the ground for thousands or even hundreds of miles as some people tend to believe. There are no huge underground rivers transporting great volumes of high purity water from Canada to Minnesota, Virginia to Florida, or from the Rocky Mountains to Iowa and other Great Plains states.

Misconception: Ground water is not a significant source of supply.
Fact: The amount of ground water in storage dwarfs our present surface supply.

Ground water is commonly considered an insignificant source of supply. The fact is, however, that the quantity of water in underground storage is 2,000 to 3,000 times larger than the amount in all the lakes, streams, and rivers combined. At the same time, it is cold, of a nearly constant temperature, free of sediment, and of high quality. The major feature of ground water is its omnipresence—it provides a reliable and economical water supply for all kinds of activities for which surface water supplies would be uneconomical or even infeasible.

In 1970, the United States was using more than 370 billion gallons of water per day. Of this amount about 20 percent was from ground water, and here lies the greatest potential for future development. About a third of all public supplies and about 96 percent of all rural domestic supplies are derived from wells. About 25 percent of the water used for irrigation is ground water. Were it not for these huge underground reservoirs, irrigation could not long exist in the arid and semiarid regions of the United States. Ground water makes possible agriculture and industry alike because it occurs at the point of use and does not require transportation for long distances.

Misconception: There is no relationship between ground water and surface water.
Fact: Ground water provides most of the flow of streams, and lakes and swamps are merely reflections of the water table.

It is commonly believed that ground water and surface water represent isolated systems. Consider, however, a stream in late summer. Although it may not have rained for several days or possibly even weeks, there may still be a considerable flow in the stream. Obviously, this water could not have been derived from the surface runoff of rainfall. In large part the stream represents water that has flowed from the ground into the stream channel. In other words, the low flow of a stream may be derived entirely from groundwater discharge.

During low-flow conditions, the chemical quality of the stream is similar to that in adjacent aquifers, but during periods of surface runoff and precipitation, the stream quality is considerably different. In many places, the quality of surface water deteriorates during the late summer and fall because adjacent groundwater reservoirs are contaminated and these contaminated ground waters provide the stream flow. It is evident that one needs to consider not only waste disposal directly into a stream but also the disposal of water-soluble material on the land surface, particularly in recharge areas. In other words, there is a close interrelationship between surface water and ground water and one cannot be managed without consideration of the other.

Misconception: The water table is falling throughout the country.
Fact: Although in a few areas the water table has declined significantly, in most places the water table rises and falls with the seasons.

Not uncommonly we read in news media that "the water table is falling." During periods of drought, when water demands increase substantially and withdrawals may exceed the rate of natural recharge, the water table may decline. In most cases, the decline is temporary and the water level recovers once the drought is over. A similar problem of declining water levels exists in particular areas, such as a few municipalities and large industrial complexes, and in extensive irrigation districts. This occurs because the rate of groundwater pumping over long periods may far exceed the natural rate of replenishment (recharge) within the area of supply. In areas of substantial water level decline, a few shallow wells may go dry or provide only limited quantities of water. Several techniques have been developed to reverse these local water level declines, but what is needed is comprehensive groundwater management programs. The water table indeed is falling in a few areas of substantial overdraft. These areas are generally very small and unmanaged. In the vast regions of the country the water level merely rises and falls with the seasons.

Misconception: The water level in a well remains constant.
Fact: The water level must decline in the vicinity of a pumping well.

The proud owner of a new well may be so enthusiastic that he believes there is no water level lowering or drawdown when the pump is on. This again is incorrect because there must be a water level decline in the vicinity of a pumping well in order to force water to flow to the well. In very permeable formations such as limestone caverns or sand and gravel deposits, the amount of drawdown may be very slight. With increasing yield, however, the drawdown increases and around high-yield wells, water level lowering may extend outward for miles.

Misconception: Spring water is synonymous with exceptional quality.
Fact: Springs are points where ground water is naturally discharging, but they are easily contaminated.

Various product advertisements assert that spring water has exceptional taste, purity, and perhaps medicinal properties. They may also imply that well water is of unacceptable quality. A spring, however, is merely a point where ground water is discharging at the land surface. It has nearly the same quality as nearby wells and streams. On the other hand, springs are easily contaminated, but the quality of well water is predictable and has nearly uniform temperature and chemical properties. Well water is biologically pure except when contaminated by sewage waste, the sources of which lie in the near vicinity.

Misconception: All well water is naturally of drinkable quality.
Fact: The mineralization of ground water generally increases with depth and eventually a point is reached where it is no longer potable.

Not all ground water is drinkable. Lying at depths ranging from a few tens to several hundred feet is the fresh-saltwater interface. Below this interface, the mineral content of the water increases substantially and at greater depths it may be so mineralized that it is considered a brine. Wells whose total depth approaches the fresh-saltwater interface eventually suffer from deteriorating quality due to the upward migration of saltwater as fresh water is removed. In coastal areas, overpumping of fresh water may cause migration of seawater into the aquifer, causing its quality to deteriorate. Adequate water management programs, however, can substantially reduce problems caused by migrating highly mineralized water.

Misconception: Since ground water can't be seen, nothing is happening to it.
Fact: We do not know the extent of groundwater contamination, but from available information we must assume that the threat of widespread contamination of ground water is substantial.

If an individual laid a raw sewage discharge line into a lake, it is quite unlikely that he would withdraw his drinking water from a surface intake only 25 feet away. The potential health problem would be easily recognized. Since ground water cannot be seen, however, the situation is considerably different. A cesspool or septic tank drain could lie within 25 feet of a well, but the potential problem might not be recognized.

Karubian[5] examined the petroleum, pulp and paper, and primary metals industries in the United States in an attempt to estimate the effect of these activities on groundwater pollution. These industries produce a vast quantity of wastewater, much of which is stored in unlined basins and lagoons. The liquids leak from the containment structures and contaminate ground water. It was estimated that the total leakage during 1973 from these structures was 192,815 acre-feet from primary metals industries, 76,335 acre-feet from petroleum refining, and nearly 134,000 acre-feet from the pulp and paper industry. Thus, the total quantity of leakage from these three industries alone amounted to more than 403,000 acre-feet of contaminated water (an acre-foot is approximately equal to 326,000 gallons). The contamination is occurring underground, is hidden from view, and is not easily recognized. Nonetheless, the problem is significant.

GROUND WATER: THE PHYSICAL FLOW SYSTEM

In order for us to understand threats to the chemical integrity of ground water, we must first have an adequate knowledge of the physical laws governing its flow through the porous route which makes up the earth's crust. The first basic situation we must consider is:

GROUND WATER FLOW TOWARD A PUMPING WELL

It is not always a simple matter for an individual to understand the process by which a well captures water. Even in our present state of scientific understanding, the average layman considers a well as a hole which taps a large underground cavity filled with water. The most obvious reason for man's ignorance of the true facts about ground water movement is simply that it is difficult to understand what one cannot see. The electron microscope has brought a whole new micro-world into focus, but the world of ground water, basic as it may be, is still often relegated to the world of mystery.

A very brief study of groundwater geology will bring to light the facts that most ground water moves through the intergranular pore spaces of sedimentary rocks rather than through broad underground channels, and that wells capture ground water by draining it from the pore spaces of saturated rocks. These facts can be best illustrated in a groundwater flow model which was constructed in order to bring groundwater flow into surroundings where it can be visually observed. The model (Figure 1a) consists of a water-tight plexiglass case containing a porous consolidated mixture of sand and epoxy resin, which simulates a true sandstone.[6] The consolidated medium is 18 inches long, 1 inch thick, and 12 inches high. Water is recharged into the right end of the model and allowed to discharge through an overflow drain in the left end of the model.

The water level in the right end tank is maintained at a higher level than the water in the left end tank. This produces a hydraulic gradient which causes the water in the model to move from right to left through the simulated sandstone aquifer. Ink is discharged into the model through a perforated metal tube buried in the right end of the sandstone. The ink entering the sand progresses through it in a thin band marking the path of flow, or flow line, from each perforation.

A ¼-inch diameter hole at the center face of the model simulates a well from which water can be pumped. When operating with the well pumping, the model closely illustrates the flow pattern of a two dimensional cross section along the regional gradient of a radial flow system. The two dimensional character of the model, however, causes the well to act something like an infinite drain channel. In either case it clearly illustrates the phenomena of gravity drainage.[2,3]

While open channel, surface water flow is characterized by turbulence which results in useless dissipation of potential energy, ground water is characterized by laminar flow which conserves all its energy for the single purpose of overcoming frictional resistance. This resistance is imposed upon the flow by the vast surface area present in the average sedimentary aquifer. When the ground water system is undisturbed, the flow will follow along nearly straight parallel lines at velocities which depend directly on the magnitude of the permeability of the rocks and on the slope of the hydraulic gradient. The pumping of a well alters the system by creating an unusually low hydraulic head at the location of the well. The magnitude and direction of the hydraulic gradient and hence the velocity and direction of the groundwater flow is changed everywhere within the area of influence of the well. The flow paths while remaining laminar will then become curvilinear as they approach the well, but a high degree of parallelism will still be maintained.

Figure 1b shows the model 23 minutes after the entrance of the ink; the flow bands have moved partly across the model under a small hydraulic gradient prior to the start of pumping. The variations in the thickness of the flow bands in Figure 1b are due to adjustments in the ink input made by the author in order to finally arrive at neat, thin flow bands. Figure 1c shows the flow bands 2 minutes after pumping began in the small well at the center of the model. The existing pressure field was modified quickly to conform to the new boundary conditions.

The coloring matter began moving slowly along an infinite set of new stream lines, which intersected the lines of the old pattern at finite angles. They finally stabilized in a pattern coinciding with the actual stream lines determined by these new boundary conditions as shown in the photograph (Figure 1d) and the flow net diagram (Figure 2). When the pump was removed, the curved flow lines moved horizontally as a unit (Figure 1e) until the

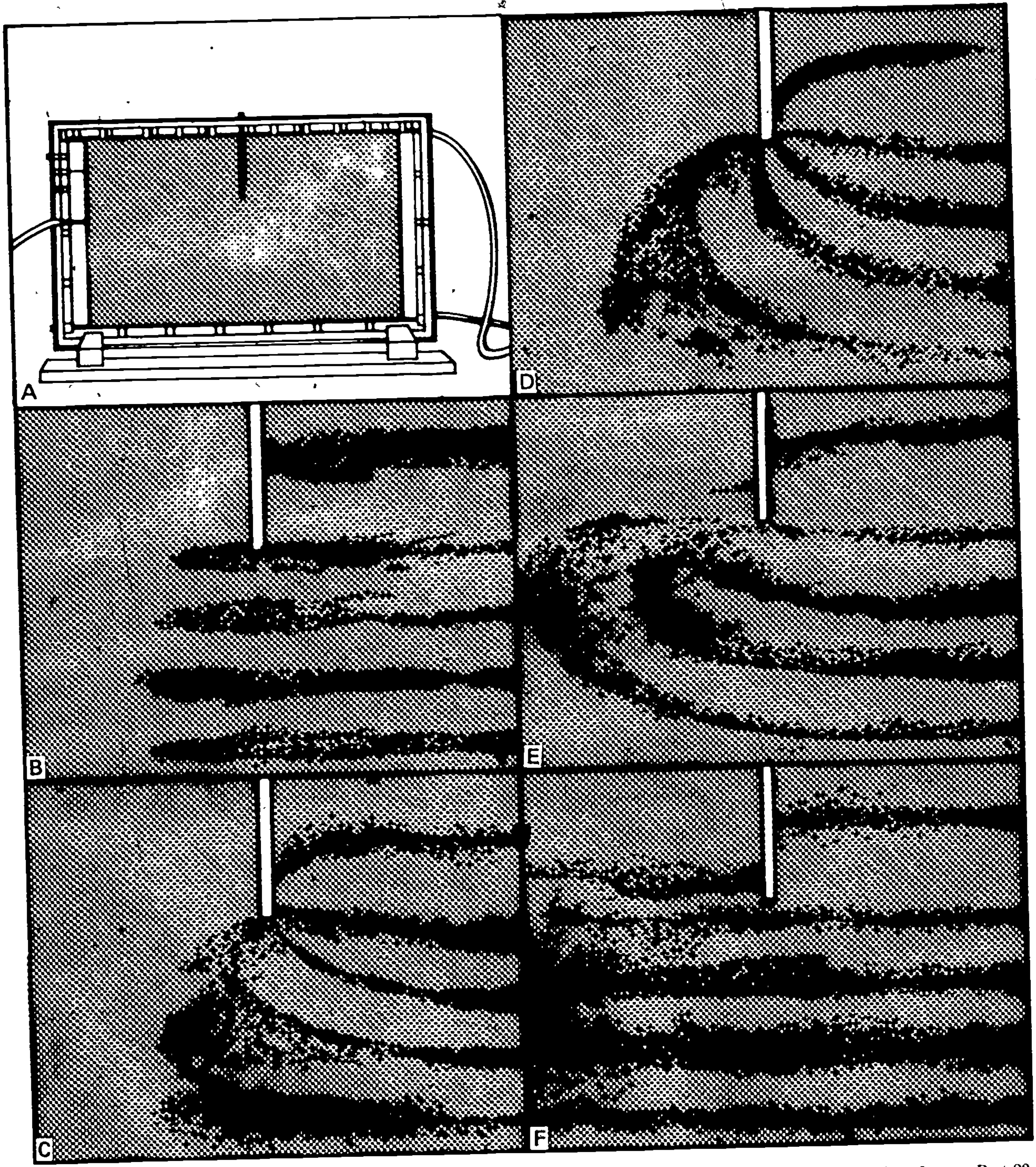

FIGURE 1 – Photographic history of a groundwater flow model. The pictures were taken at the following times. A at 0 min.; B at 23 min. after the entrance of ink, C at 2 min. after pumping began (24 min. after entrance of ink); D at 10 min. after pumping began, E at 6 min. after pumping stopped (pumping had continued for 11 min.), F at 25 min. after pumping stopped. Photographs B through F are enlargements of the porous consolidated medium shown in A.

ink was flushed out of the model and only the horizontal bands appeared (Figure 1f). Here an almost instantaneous change in the vectors of motion of the water particles took place because the reaction time is very fast in small models. In the nonpumping situation all the vectors were approximately equal, hence the old flow bands appeared to move as a unit.

The most interesting observation made in the study of this model (Figure 1) was the complete lack of a transition phase of the flow bands as they appeared before pumping, and as they appeared after pumping had taken place for a few minutes. At almost the very instant the well began to pump, all the particles of water within the radius of influence of the well acquired a new vector of motion. There was no realigning of old flow bands because the old flow bands ceased to exist when pumping began. Each particle of water was on its own to take its place in the new net, similar to individuals in a marching band when a new formation is imposed.

The change in the flow net is dependent upon the water level in the pumping well. Any change in boundary conditions in the system, such as drawdown in a well, will be felt throughout the system resulting in adjustments of the pressure distributions in accordance with the new boundaries.[11] The speed with which these adjustments occur can be determined by the Theis non-equilibrium/equilibrium equation [12]

$$s = \frac{114.6\ Q}{T} \int_{Z}^{\infty} (e^{-u}/u)\ d\ u$$

s = drawdown at any point, in feet
Q = rate of discharge of the well in gallons per minute
T = coefficient of transmissibility, in gpd per ft.

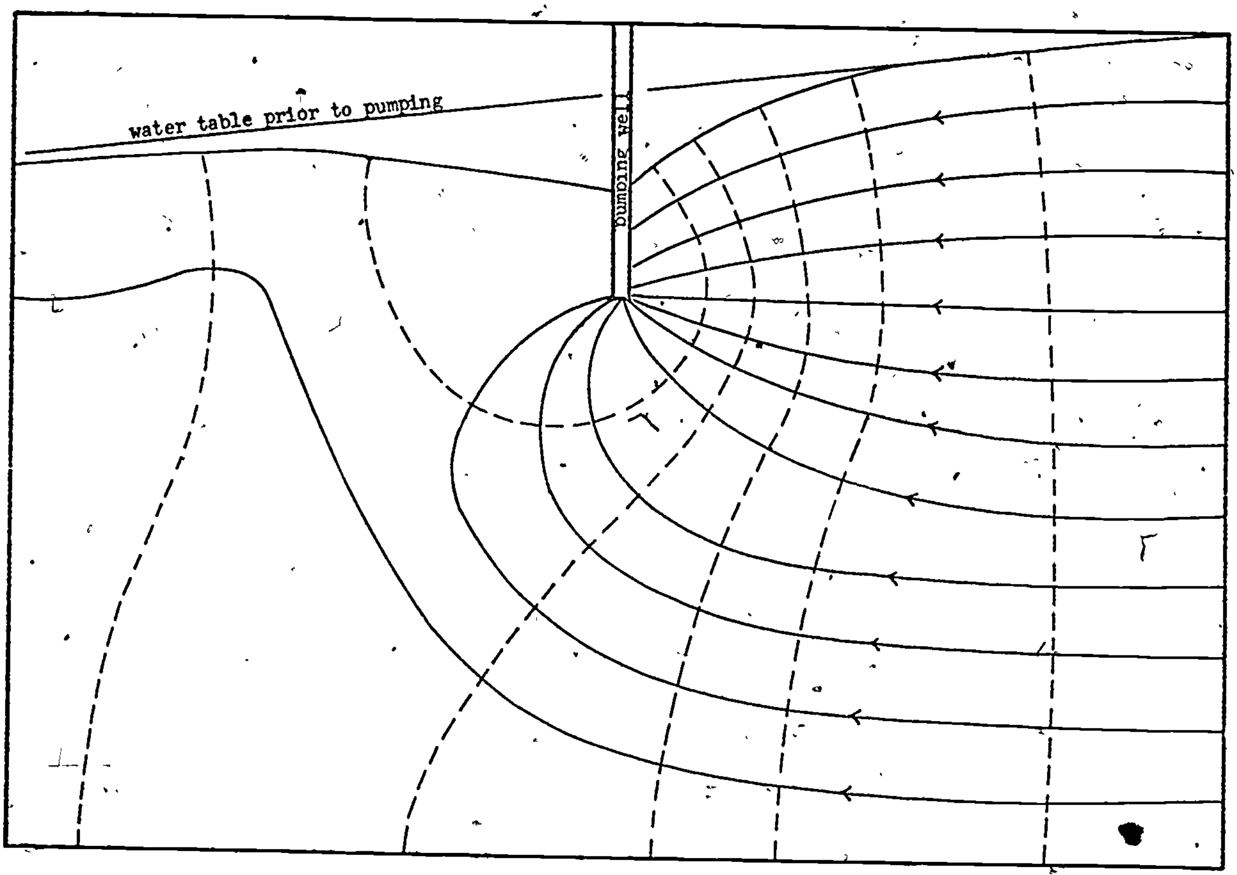

FIGURE 2.—Flow diagram of well model shown in Fig. 1. The path which a particle of water follows is called a flow line; these are represented by solid lines with arrows. The head decreases along the path of flow. Lines connecting points of equal head are called equipotential lines; these are represented by dashed lines. An unlimited number of flow and equipotential lines can be drawn in any flow system; however, in a flow diagram a finite number of lines suffice to best illustrate the general pattern of flow. (Scale = 1/2 actual model.)

$$Z = 1.87 \frac{r^2 S}{T t}$$

r = distance between pumped well and point of observation, in feet
S = coefficient of storage, dimensionless
t = time the well has been discharging, in days
u = a dimensionless quantity varying between the limits given

This equation was derived upon the simplifying assumption that the removal of water from an aquifer is exactly analogous to the removal of heat from a metal plate, for which the equations are already known.

Study of the flow pattern surrounding a pumping well is important to the problem of water quality. In many locations the quality of water will vary with depth. Water at different depths may have originated from separate source areas and moved through rocks of different chemical composition, thereby being exposed to the solutioning of dissimilar ions. Often the water at certain depths in a specific location is potable while at other depths it is not. A careful predetermination of the flow near the proposed supply well will delineate the vertical zone from which water will be captured. This will insure avoiding any contamination by poor quality water.

The limits of the well's area of influence should also be determined for most wells, especially where there is a possibility of groundwater contamination. In some areas, such as Long Island, N.Y., industry is obliged by law to return water used only for cooling purposes to the groundwater body. The used water is very warm, and care must be taken not to allow this water to heat up the fresh supply of water being used for cooling. If this is allowed to happen the water used for cooling purposes will be warmer to begin with and, therefore, will do a less efficient cooling job which will result in higher cost to the industry. By studying the flow net surrounding the pumping well, it is possible to determine how far distant a recharge well must be placed in order to prevent the recharge water from returning to the discharging well.

ANALYSIS OF WATER TABLE DRAWDOWN SURROUNDING PUMPING WELLS

Having considered the flow pattern to a pumping well, it is now necessary to study the effects of pumping on the level of saturation or "water table." It is important to understand that all the ground water within a single set of hydrologic and geologic boundaries is part of a single hydrologic system. Changes in any part of it will eventually modify conditions throughout the entire system.

A hydraulic model analogous to very general subsurface geologic conditions was constructed for the purpose of studying and demonstrating the changes in the configuration of the water table produced by pumping wells.[8] The model consisted of a watertight plexiglass case containing a consolidated medium, which was a mixture of sand and epoxy resin. The model case was made of plexiglass ½-inch thick; the inside dimensions were 33 inches by 12 inches by 3 inches.

The medium at the extreme right of the model was impermeable and was intended to represent the subsurface portion of an igneous mountain front. The remaining medium within the model had a rating of approximately 2,000 Meinzer units (gallons per day/foot.^{2}, 1:1 gradient). The left end tank of the model was intended to represent the cross section of a stream channel into which water was recharging; the sloping top surface of the porous consolidated medium was intended to represent a tributary channel capable of leading runoff from the mountain front to the main stream channel. The model contained 30 wells that accurately measured the position of the water table. All of the wells were ¼-inch in diameter. The lowest 6-inch segment of the four deepest wells was screened; the rest of the wells were open only at the bottom. A small bead of red wax was placed in each observation well so that the water level would be clearly visible.

Figure 3 shows the model before and after well B had been pumped for a long enough period to achieve a steady state condition. The white line marked "static water level" illustrates the position of the water table before pumping. The definite effects of the boundary conditions upon the cone of depression are shown by the black line on the model. The limb of the cone to the right of the well was almost flat, due to the effect of the impermeable boundary on the right. Since the well was unable to take water from storage beyond this impermeable barrier, it was forced to take an increased amount of water from storage in front of the barrier. This resulted in the lowering of the cone of depression in that area. The cone of depression at the left of the well extended to the surface of the recharging water. At that point enlargement of the cone ceased, for recharge from the end tank was induced and the necessity for drawing additional amounts of water from storage within the aquifer was eliminated. This is exactly what happens when a well being pumped near a stream extends its cone of depression to the edge of that stream.

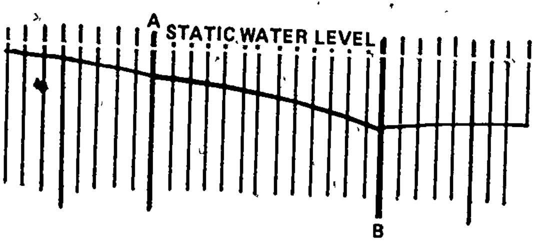

FIGURE 3.—Photograph of the cone of depression model after pumping in well B had reached a steady state. The cone of depression is drawn in black.

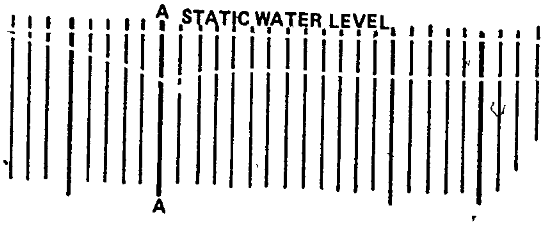

FIGURE 4.—Photograph of the cone of depression model after pumping in well A had reached a steady state. The cone of depression is drawn in white.

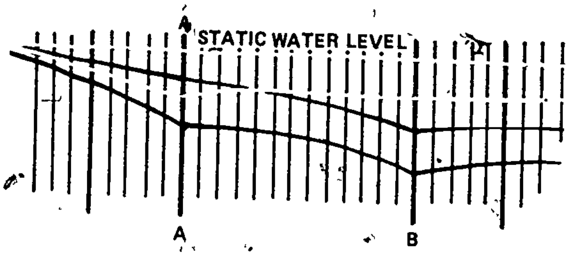

FIGURE 5.—Photograph of the cone of depression model after pumping in wells A and B had reached a steady state. The existing multiple cone of depression is drawn in gray, while the individual cones of depression of wells A and B (as shown in Figs. 3 and 4) are drawn in white and black, respectively.

Figure 4 shows the model after well A had been pumped for a long enough period to achieve steady state conditions. The surface of the cone of depression is drawn in white on the face of the model. Once again, the effects of the two boundary conditions are evident. In this case, the effect of the source of recharge was more intense than the effect of the impermeable barrier, for well A was closer to the recharge tank than to the barrier.

In a multiple well system where surface recharge and evaporation are negligible, the drawdown at any point within the area of influence is the sum of the individual drawdowns of each well in the system.[14] The results of investigations with the model verified this statement. When wells A and B were simultaneously pumped long enough to reach the steady state condition (Figure 5), the composite cone of depression was the sum of the individual cones. Both wells were pumped at the same rates as those used to obtain the information depicted in Figures 3 and 4, respectively. The black line on the model in Figure 5 represents the individual drawdown caused by pumping well B (as shown in Figure 3); the white line represents the individual drawdown caused by pumping well A (as shown in Figure 4). The gray line on the model represents the drawdown caused by the simultaneous pumping of the two wells. It is readily apparent that the vertical distance between the gray line and the static water level is equal to the sum of the vertical distances between (a) the white line and the static water level and (b) the black line and the static water level.

This hydraulic model also can be used to study artificial recharge by wells. Because this practice is being widely used today, it is important that the effects of such recharge upon the shape of the water table be clearly understood. It has been proved theoretically that the cone of impression brought about by a recharging well will be a mirror image of the cone of depression formed by pumping the well at the same rate as it is recharged.[1] An experiment was performed with the model to verify this relationship; the results of the tests are shown in Figure 6. The upper section of Figure 6 is a photograph of the model prior to pumping; the white line represents the static water level. The center section of the figure shows the model after well B was pumped long enough to reach the steady state. Pumping was then stopped until the water level recovered to the static position; at that time recharging was begun at the same rate that the well had been discharging. The lower section of Figure 6 shows the model after the steady state conditions had been reached. It is readily apparent that the cone of impression, drawn in gray above the static level, is the mirror image of the previously formed cone of depression, drawn in gray beneath the static water level.

The principles demonstrated with the cone of depression model have important implications in applied hydrology. One concept illustrated by the model is that it is advantageous to place a pumping well as near as possible to a source of recharge. Prior to development by wells, most aquifers are in a state of dynamic equilibrium, that is, natural discharge is equalled by natural recharge, and the quantity of water in storage remains essentially constant.

When wells tap an undeveloped aquifer, a new discharge is superimposed upon a previously stable system. This must be balanced by an increase in

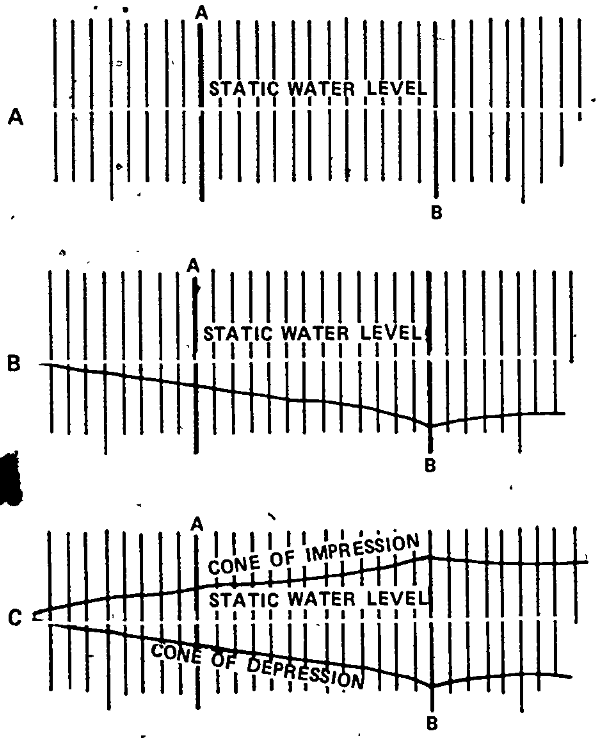

FIGURE 6.—Photographs of the cone of depression model A under static water level conditions; B after pumping in well B reached a steady state; C after recharging into well B reached a steady state.

natural recharge, a decrease in natural discharge, a decrease in storage, or a combination of all three. The system is temporarily in a state of non-equilibrium until discharge from it again equals recharge. The ultimate cone of depression of a pumping well is the mechanism through which the recharge and discharge are equalized. When the cone of depression reaches a recharge area where recharge previously was being rejected, it causes an increase in the natural recharge by steepening the gradient. When the cone of depression reaches a natural discharge area, it decreases the gradient and hence decreases the quantity of natural discharge. When a well is placed close to an area of rejected recharge, such as a stream or swamp, its cone of depression rapidly reaches the recharge area and induces increased natural recharge. Only a very shallow cone of depression is required in this case; well A in Figure 2 illustrates this fact. When a well is placed far from the recharge area it will take longer for the cone of depression to reach it and hence a deeper cone will result; such a situation is shown in Figure 3.

Although groundwater users may put their water to work in many different ways, it is surely in the best interests of all that the common water supply be conserved so that it will yield the optimum quantities of water at the most economical rates. A thorough understanding of the physical principles which govern the performance of a groundwater system will lead to more efficient planning and use of water. Study of the various configurations of the water table brought about by the pumping of water table wells will definitely help groundwater users understand their individual positions in the regional groundwater system.

A most important fact illustrated by the model is shown when it is assumed that wells A and B (Figure 5) are owned by different farmers. Both of the owners must realize that when either well is pumped the water level at both wells will be affected. Thus, because the subsurface aquifer along with its areas of surface water recharge and discharge is an integrated system, it must be jointly controlled and operated by all water users if the optimum benefits of its water supply are to be gained.

Ground Water: Flow Toward An Effluent Stream

One of the most interesting groundwater flow patterns in nature occurs in the vicinity of an effluent stream, a stream which is supplied by the surrounding ground water. Legal disputes have arisen from misinterpretation of information about the flow patterns near such streams. Water levels in wells drilled along an effluent stream can be higher than the water level of the stream, and this fact has been submitted as evidence that ground water and surface water are not connected.[10] Once established as a fact in court, a decision can be obtained in some States that action taken upon the groundwater body cannot possibly have any effect on the surface water body. Such a stand may be taken by a ground water user to prove that pumping cannot deplete surface water. A groundwater user could similarly argue that he cannot contaminate surface water by discharging waste into his well. Results derived from a hydraulic model,[7] analogous to the geologic setting commonly found near an effluent stream, show that such arguments in many cases may be spurious. Only by adequate definition of both the geology and hydraulics near the stream can the courts render sound judgment on such matters.[13]

The model (Figure 7) consists of a watertight plexiglass case containing a porous consolidated mixture of sand and epoxy resin.[6] It is 30 inches long, 1 inch thick, and 12 inches high at each end and slopes down to a small channel near the center. The channel represents the cross section of the effluent stream. Ink was discharged into the model through a perforated brass tube buried in each end. The ink entering the sand progresses through it and marks the path of flow, or flow line, from each perforation. Water was recharged into both ends and discharged only from the simulated stream. The water table nearly coincided with the rock surface on either side of the stream. Figure 7 indicates the general direction of flow at several times after the flow of ink was started.

The flow lines turn up near the center and appear to defy gravity. Although the water is definitely flowing upward topographically, it is flowing downward hydraulically in accordance with physical principles. Ground water always moves from regions of high hydraulic head to regions of low hydraulic head.

The effluent stream may be compared with a horizontal well. In a manmade well, an area of low head is produced by pumping and the ground water thus flows from the surrounding areas of high hydraulic head to the region of lower head near the well. The effluent stream is also an area of low head, but the head distribution about the stream is a function of the topography and rainfall which have caused a high water table to form; a region of high hydraulic head surrounding the topographically low-stream channel is thus furnished. Consequently, water moves from the adjacent highland into the stream.

Figure 8 shows the flow diagram of the effluent stream model. Flow follows the direction of maximum gradient as a ball takes the steepest path when rolling slowly down a hill. Since the gradients are maximum along paths normal to the equipotentials, the flow lines cross the equipotential lines at right angles and thus form a conjugate system. The equipotential lines beneath the stream become horizontal as they connect points of equal hydraulic head on opposite sides of the stream. The ground water flow which crosses these equipotentials at right angles must therefore move vertically upward in this region.

The increased potential with depth beneath the effluent stream was verified in the model. Two wells were drilled in the stream channel and screened at different depths. The water levels in the wells rose to different heights above the level of the stream itself. The deeper of the two wells had the higher water level which indicates the high potential at greater depth.

Comparison of the rates of movement of the flow lines (Figure 7) shows that the flow along the base of the aquifer is much slower than at points higher

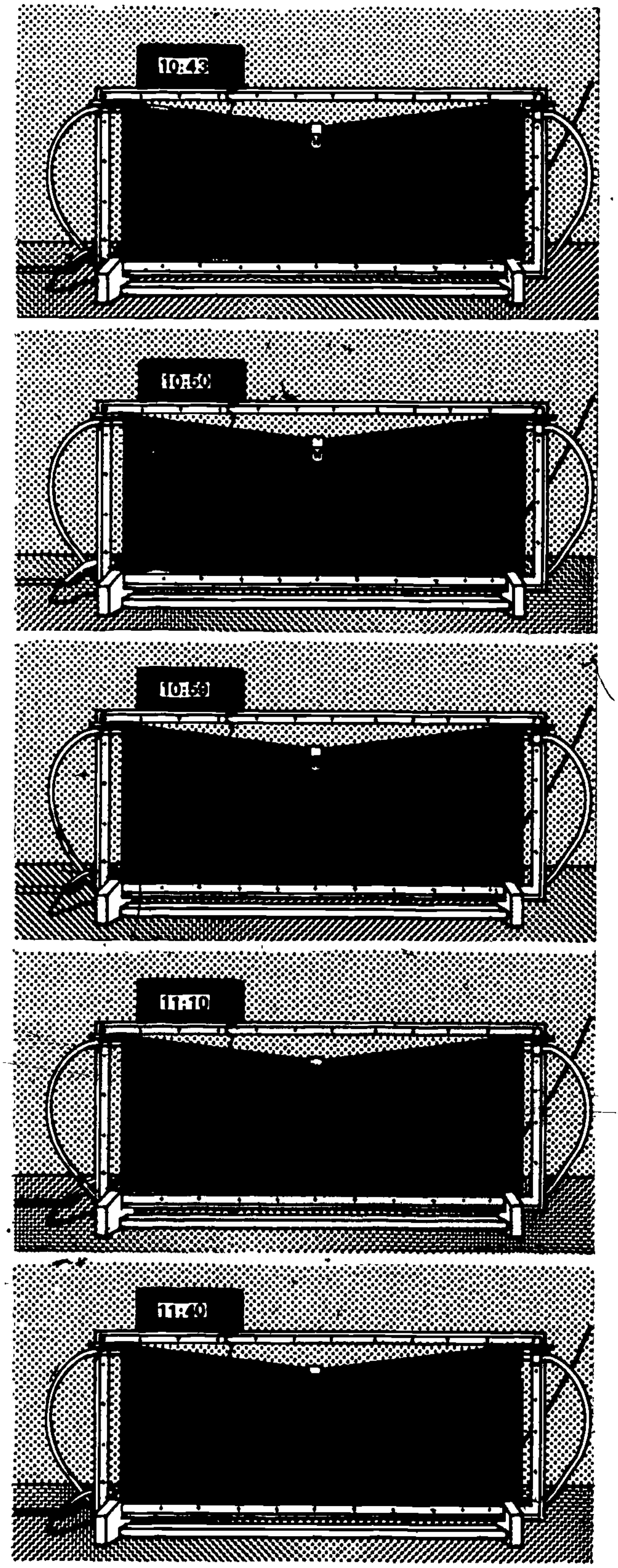

FIGURE 7

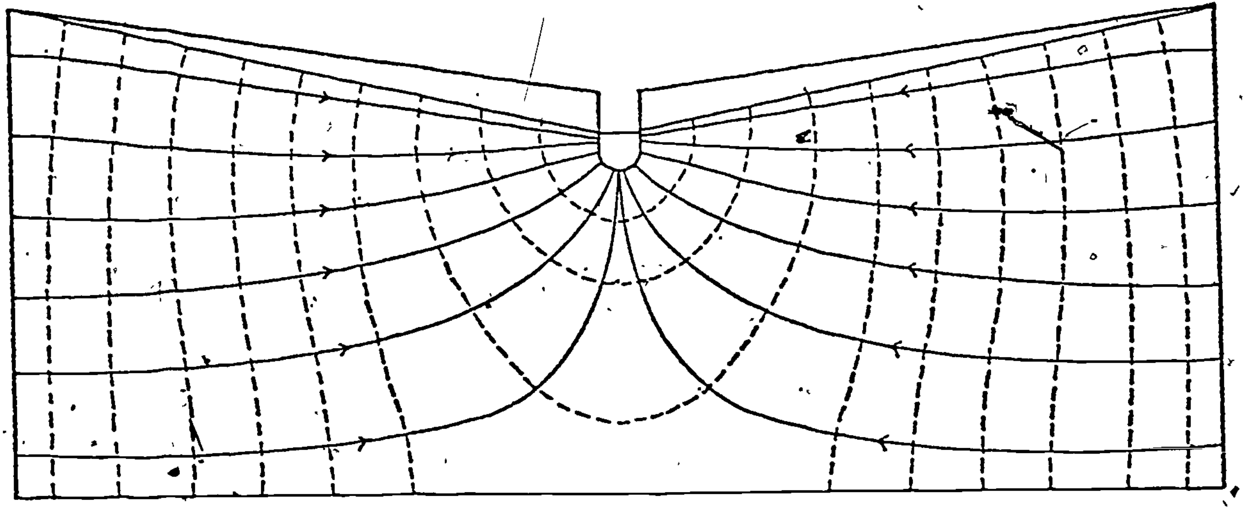

FIGURE 8.—Flow diagram of effluent stream model shown in Fig. 1. The path which a particle of water follows is called a flow line; these are represented by solid lines with arrows. The head decreases along the path of flow. Lines connecting points of equal head are called equipotential lines and are indicated by dashed lines. An unlimited number of flow and equipotential lines can be drawn in any flow system; however, in a flow diagram a finite number of lines suffice to illustrate best the general pattern (about 1/4 actual size).

in the model. This knowledge is very important in studying streams near the sea which are subject to onshore winds and saltwater tides. The saltwater may move up the stream during a storm and raise the water level, and thus temporarily reverse the groundwater gradient. During this temporary flow reversal, saltwater moves from the stream into the groundwater body and because of its high density may eventually sink to the bottom of the formation.[4] A saltwater mound is thereby formed beneath the stream channel; this mound may have a long-lasting, detrimental effect on water supply wells in the deep portion of the aquifer near the stream channel. Although the original groundwater gradient may be resumed soon after the stream subsides, a long time will be required to wash out all the salt by the comparatively slow movement of ground water through the deep zone. A town's water supply can be temporarily impaired beyond use by this phenomenon, but this occurrence can be avoided if water supply wells are placed at a safe distance from the bank of any stream subject to salt water tides.

ANALYSIS OF GROUNDWATER FLOW AROUND AND THROUGH LENTICULAR BEDS

Regional groundwater patterns may be effectively altered by the presence of lenticular beds intersecting the general direction of flow. The manner in which these lenses can affect the normal flow has often been misunderstood by people involved in the utilization of groundwater resources. A model experiment was performed[9] in order to study the flow patterns around and through lenses of different lithologies.

The horizontal model,[6] Figure 9, 18 inches long, 12 inches wide, with an inside thickness of 1 5/8-inches was utilized for this purpose. The model has a 3/8-inch plate glass top and bottom, while the sides are sealed with opaque epoxy resin. Aluminum reservoir tanks, 3 inches deep, are attached at each end, extending out 2 inches from the model. A 12-inch strip of 1-inch aluminum angle bar is bonded to the glass top at each end so that the water levels in the reservoir tanks can be maintained above the level of the model to produce a confined flow system. The model contains porous consolidated mixtures of sand and epoxy resin, simulating sedimentary rocks, which have been formed into a pattern representing a particular geologic structure. The oblate lens shown on the right in Figure 9 has a coefficient of permeability of less than one USGS unit (gpd/sq ft/1:1 gradient). The eliptical lens on the left has a coefficient of permeability of 10,000 USGS units, and the encompassing medium has a permeability of 2,000 USGS units.

Figure 9 shows a plan view of the model as ink flow bands, emanating from ink reservoir cups attached to the right end of the model, moved through the porous consolidated medium under a small hydraulic gradient. It is interesting to note (Figure 9) that flow band No. 3 in the center bifurcated, completely wrapped around the oblate lens, then reunited into a single flow band and continued toward the second lens. Flow bands Nos. 2 and 4 were forced outward by the effect of the impermeable lens but were then attracted toward the center of the second lens because of its great permeability and large capacity for transmitting water. As the flow bands left the second lens they again spread due to the decreased transmissibility of the encompassing medium.

Many persons believe that a small area down-gradient from an impermeable lens will be a dead area with no flow moving in or out. This model experiment supports the fact that there are no dead spots or stagnation zones in saturated laminar groundwater flow.

There is, however, a point of zero velocity, or no flow, called the stagnation point, which may occur within a flow system. When flow bands bifurcate or unite around some boundary condition, such as the impermeable lens in Figure 9, or a cone of depression of a pumping well,[14] there will be a point around which the flow lines, contiguous to the boundary, pivot as the direction of flow is changed. This point is called the stagnation point. It has no area or volume, but is simply an infinitesimal point. When considered in three dimensions the point becomes a series of points on a line. With the exception of these stagnation points, there is a positive velocity vector acting everywhere within the pore spaces of a saturated porous medium when a hydraulic gradient is imposed upon it. However, although all the water in the system will flow, the velocity of flow will not necessarily be constant throughout the porous medium. This can be seen in Figure 9, where all the ink bands were injected simultaneously into the model, but flow bands Nos. 1,2,4, and 5, at the sides of the first lens, traveled at greater velocities than band No. 3 which began directly behind the lens. In this model the water immediately down-gradient from the impermeable lens was definitely not stagnant or motionless. The water flowed very slowly from this area and was

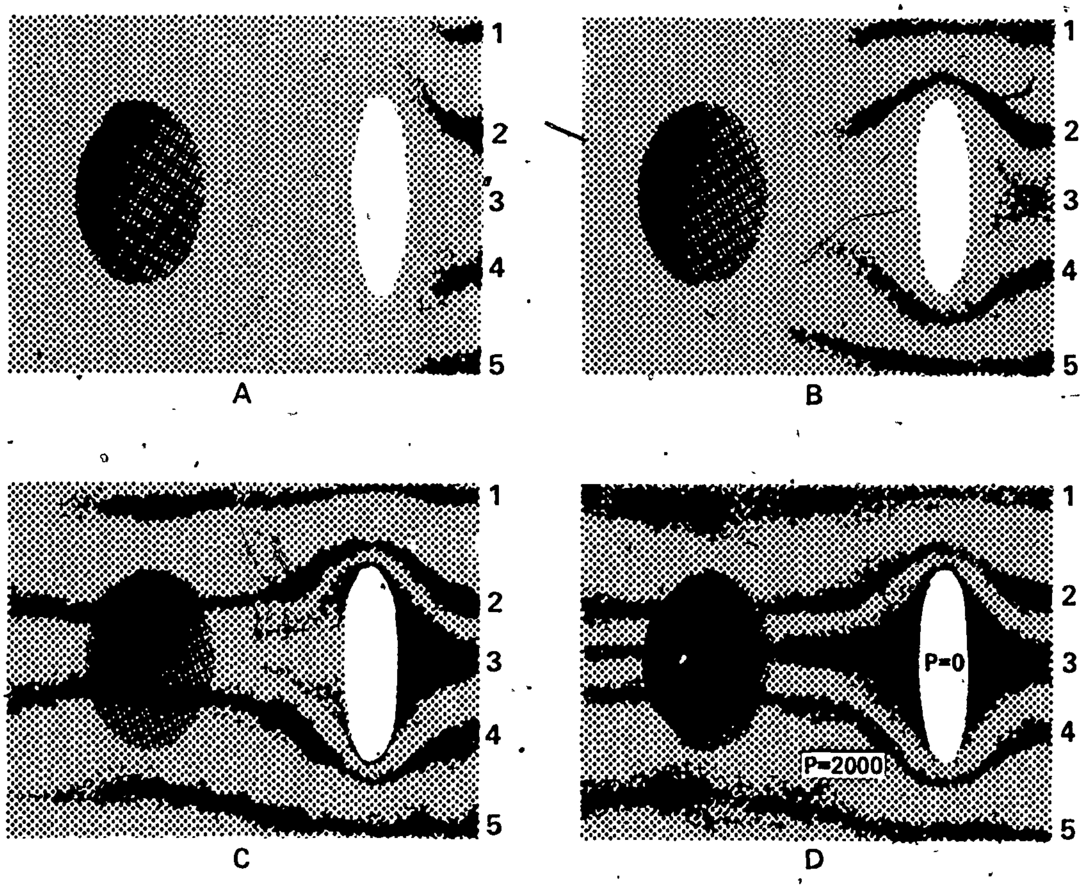

FIGURE 9. – Photographic history of the horizontal lens model. The pictures were taken at the following times after the entrance of the ink: A at 6 min., B at 18 min., C at 34 min., and D at 44 min.

continuously replaced by water flowing from a position of higher potential in accord with the equation of continuity:

$$Q = A\Theta V$$

where Q = volume rate of flow,
A = cross sectional area normal to flow,
V = velocity of flow, and
Θ = porosity of porous media.

The flow diagram of the lens model appears in Figure 10. The path which a particle of water follows is called a flow line; these are represented by solid lines. The head decreases along the path of flow. Lines connecting points of equal head are called equipotential lines; these are represented by dashed lines. An unlimited number of flow and equipotential lines can be drawn in any flow system; however, in a flow diagram a finite number of lines suffice to best illustrate the general pattern of flow. As previously stated, flow follows the direction of maximum gradient, much the same as a ball will take the steepest path when rolling slowly down a hill. Since the gradients are maximum along paths normal to the equipotentials, the flow lines cross the equipotential lines at right angles, thus forming a conjugate system.[11]

If flow lines are first drawn at equal intervals along a known equipotential line, the quantity of water flowing between any two flow lines will always be equal, assuming a unit depth, with no additions to or losses from the saturated system. If head loss between all adjacent equipotential lines is maintained constant, then the flux of water moving through every element of the net bounded by two flow lines and two equipotential lines will be equal. This system of constant density flow lines and equipotentials is utilized in the flow net in Figure 10.

The change in thickness of flow band No. 3 as it moved around the first lens is of considerable interest (Figure 9). It was a thick band, both in front of the lens and behind it but, as it rounded the corner, it was very thin. In order for this to occur in homogeneous media, the velocity of flow must be much greater where the band is thin than where the band is thick, in order to satisfy the continuity equation; that is to say, when Q remains constant, V must increase as A decreases. The flow diagram of this model (Figure 10) designates these velocity variations by the changing dimensions of the flow net elements. Within a single medium, the velocity is greatest in the narrowest elements and lowest in the widest elements.

A great deal can be learned from this model in regard to the proper placement of wells seeking uncontaminated water. Many mistakes have been

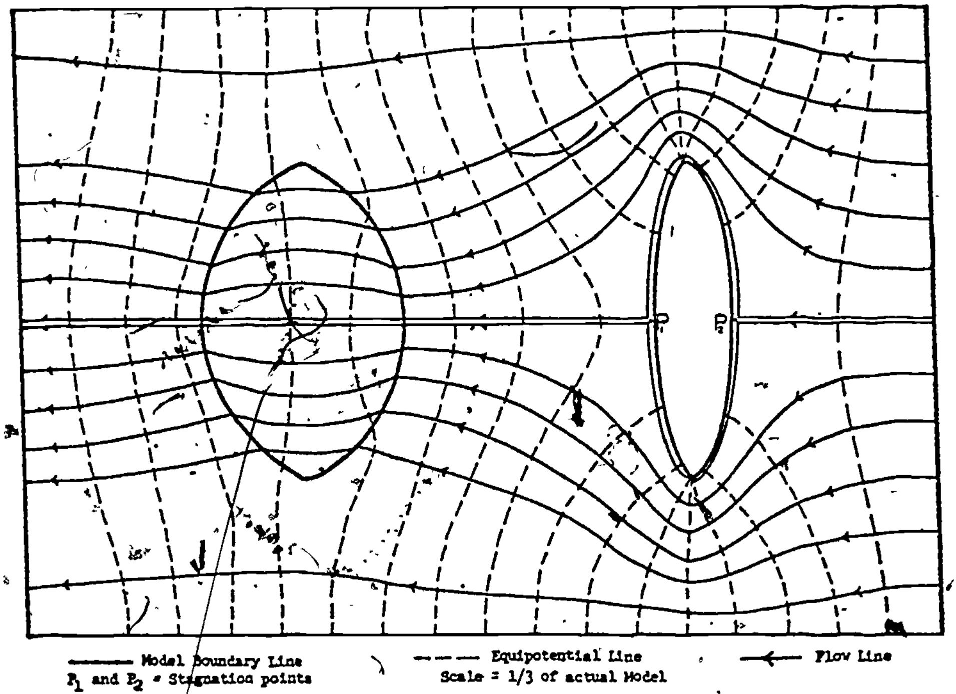

FIGURE 10.—Flow diagram of the horizontal lens model shown in Fig. 1.

made in the placement of wells in areas of known toxic waste disposal. One common misconception is that the shadow of a low or impermeable formation, such as an igneous plug or stock down-gradient from a point of waste disposal, offers a water supply safe from contamination. This model indicates that this so-called shadow area only offers a delay rather than an escape from the inevitable contamination. In contrast to this observation is the excellent possibility of obtaining relatively uncontaminated water at some distance to the right or left of the high permeable lens. When such a lens occurs directly down-gradient from the location of the waste disposal, it may have the effect of concentrating the waste fluid in a small cross-section of flow, leaving the area to the sides of it uncontaminated and, therefore, capable of supplying potable well water.

GROUND WATER: MAINTAINING ITS CHEMICAL INTEGRITY

In the previous sections of this paper we have examined the physical characteristics of ground water movement and concurrently touched on a few of the potential pollution problems which may alter its chemical quality. Let us now examine more generally many of the additional ways that ground water becomes contaminated and then consider potential methods by which groundwater contamination can be controlled or at least decreased.

Groundwater pollution is caused by man's activities—excessive pumping from coastal wells, irrigation, manufacturing, mining, and many others, but most importantly, groundwater pollution is caused by poor or inadequate waste-disposal practices. Waste materials are commonly disposed of by placing them in streams, on the land surface, or in the ground.

Wells near streams cause the water to flow from the stream into the ground, and thence to the well. If a stream is grossly polluted, this undesirable water may contaminate nearby ground water and wells—but it may take several years for the polluted water to show up at the well and by that time perhaps the entire area between the stream and the well is contaminated.

This type of groundwater pollution can be reduced by prohibiting the dumping of noxious chemicals and other wastes into streams. Strict enforcement of surface water quality standards, which already exist, will go a long way towards a solution of this problem.

Man commonly spreads wastes on the land surface and stockpiles raw materials or finished products outside. Many of these substances contain chemicals that dissolve in water—in rain or surface runoff. Once dissolved, the highly mineralized or polluted water may slowly sink into the soil, leading to groundwater pollution.

Examples include dumps, manure piles, mineral ores, stockpiles of salt for snow removal, and hundreds of others. Animal feedlots have contaminated ground water with excess amounts of nitrate—a health hazard. Stockpiles and salting of roads in winter have caused well supplies to taste salty. And groundwater contamination by leachate from dumps has caused foul tastes and odors.

Groundwater pollution caused by spreading wastes on the land and stockpiling other materials can be lessened by the development of state regulations controlling such practices. Open and unregulated dumps should be prohibited. Stockpiles should be covered or drainage ditches constructed around them so that the runoff can be collected and treated. Permits should be required but issued only after considerable thought and evaluation of the potential consequences. In many instances, bonds should be required which would be forfeited if the operation isn't managed properly. The operator could be held criminally liable if groundwater pollution occurs. All of the regulations should be based on sound scientific principles.

Unquestionably the most serious and widespread causes of groundwater pollution are related to the storage or disposal of wastes in the ground—primarily by septic tanks and secondarily by holding ponds and lagoons. The wastes filter down to the water table and may later be withdrawn from a well. The same is true with outdoor privies and cesspools, waste disposal in excavations and sanitary landfills. More insidious, and in some ways more dangerous, is the leakage through ruptured and corroded storage tanks and transmission lines of materials such as gasoline, fuel oil, and radioactive wastes.

Wells contaminated by privies, cesspools, or septic tank wastes can lead to waterborne diseases and epidemics at the worst, or the water may have bad tastes and odors or even produce soap suds! Toxic compounds such as chromium and organic chemicals have appeared in wells because the ground water was contaminated by wastes from holding ponds or lagoons. The disposal of oil field brines in holding ponds or evaporation pits has led to the pollution of literally thousands of sites with salty water. The contaminated water may be so corrosive that plumbing in pumps literally falls apart, and if the water is used to irrigate a lawn or garden, all of the vegetation dies.

The effects of drinking water contaminated by radioactive wastes are very subtle and may require long periods of time to become evident, but leakage of gasoline into the ground has led to taste and odor problems which are minor compared to the destruction brought about by explosions and fires. In a few cases, gasoline floating on the water table has leaked into basements where the fumes were ignited by pilot lights or sparks.

Many of these groundwater pollution problems cannot be easily solved but controls can be developed so that future problems are minimized. Domestic waste disposal will be less of a problem if State agencies develop strict guidelines on septic tank spacing and prohibit the use of outdoor privies and cesspools. Industrial and municipal holding ponds and lagoons should, in most situations, be lined with material that will halt the slow infiltration to the water table. The ponds should be protected by dikes and alternate containment facilities and before a permit is issued methods should be available for the control and cleanup of groundwater pollution in the event that it should occur. Performance bonds and stiff fines coupled with stringent permit procedures would go a long way towards proper waste disposal management.

There are many other causes of groundwater pollution.

Problem: The leakage of highly mineralized or polluted water through unplugged abandoned wells and exploratory holes or through improperly constructed wells.
Control: Adequate water well construction standards. State requirement that all abandoned wells and exploration wells be properly plugged.

Problem: Drainage wells and collection sumps are designed to drain swampy or water-logged land so that the water flows deeper into the ground or to collect spilled materials. Much of the drainage water and spilled substances are highly mineralized and sink from the wells and sumps into water-bearing strata.
Control: Prohibit the use of drainage wells and collection sumps except for domestic use, or require a permit procedure under strict guidelines.

Problem: In some instances, water supplies are contaminated by accidental spills, such as truck or train wrecks.
Control: Obviously, it is not possible to prohibit accidents but it is possible to consider if the materials are being handled in the safest manner possible. Furthermore, it is also possible to develop quick cleanup techniques. This should be done.

There are many sources of groundwater contamination. In order to visualize whether a certain process or activity may cause groundwater pollution, one has to ask himself only one question—does the product or waste material contain water-soluble substances. If it does, then there is a good chance that groundwater pollution may occur if adequate precautions are not followed.

Although the final responsibility for the development of adequate regulations to protect our groundwater resources rests with State and Federal agencies, the average citizen must get involved in order to recognize and press the issues. After all, we all drink water, we must have it to survive, and at least part of the responsibility for its safeguarding rests on our shoulders.

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DISCUSSION

Comment: What is your definition of integrity of ground water? Is it zero for further contamination? Or, you jokingly said that some streams could be sewers or some aquifers that have terrible quality of water—

Dr. Lehr: I feel exactly that way. There are indeed aquifers that have poor quality of water naturally, and in no foreseeable future could they ever be used as potable supplies and I think there's no reason why we cannot dispose of our wastes into them.

They're generally very deep. They have salinity greater than 100,000 parts per million and we should be able to develop and construct really super disposal wells. The regulation in doing that is very severe, but when done right it's terrific and I think we can consider them sewers and dump our water into them.

The standards for maintaining the integrity of potable aquifers, aquifers that can be used for drinking water today or with a little cleaning in the foreseeable future should be the same as surface water. In other words, the drinking water standards, as best we define them, should be used.

Comment: I was wondering if you could explain deep well disposal and, secondly, pretreatment for deep well disposal of effluents.

Dr. Lehr: Well, deep well disposal is the emplacement of pollutants purposely in the ground through deep wells. You don't ever want to do it on the surface or anywhere near the surface but you can use zones that are already unusable and are not assumed to ever be usable for one reason or another. The pollutants will be stored there and will not migrate any great distance at a later time and get into usable water. We know so much about ground water, we can chart the movement of these underground formations and we can tell if the pollutant is placed properly and the well casing doesn't leak upward and that the deep zone is not hydraulically connected to a surface water zone by some fault or crack in the rock or high permeable zone that moves vertically downward. Then we know that this pollutant is going to be out of our way for hundreds of years effectively, and we have a good place to put the waste. It is done, it can be done, but more often than not it's done poorly and they leak and cause side effects and sometimes the wells blow out of the ground because the pressure is so great.

A certain amount of pretreatment is generally needed so as not to plug up the deep zone of rock. As far as potash goes, I don't know specifically—I mean I know what potash is and I'm not aware of any potash disposal wells and possibly through my ignorance I don't see any reason why one could not dispose of potash or anything else.

We know we can dispose of radioactive wastes this way if it's done properly. Sometimes without too much worry if the half-life is reasonable like 50 or 100 years; if it's very long, we want to make sure we do a good job. But it can be done and I don't know whether I'm something of a renegade in the groundwater field, but I'm a realist as a ground water person because the crust of the earth has gigantic volume. It's absurd to think we've got to protect it all for drinking water. It's a multipurpose system.

Comment: Many of us are aware of problems with older sewer systems, specifically, infiltration. Would you comment, please, on the problem of exfiltration in those systems that are above ground water.

Dr. Lehr: Yes. This is a tremendously serious problem. In a lot of areas where you could use individual domestic systems, where you have good soil and you could use septic tanks or aerobic systems and you're somewhat short on ground water, municipal sewer systems can do a lot of damage for two reasons: when they're poorly constructed, and they're all poorly constructed, they have negative pressure; that is to say, you always build a sewer system so it doesn't leak into the ground water, you build it so the ground water leaks into it, so you get a tremendous inflow of ground water into the sewer system and frequently you lower the water table, making less water available for use from wells and, what is even worse, you increase the load on your sewer, your water treatment plant, because you're putting in this perfectly good water, diluting your sewage and then you've got to treat it all and you've really got more volume than you can treat.

Then in periods of high flow you let it run out into the river anyway so this is a problem and when you are going to build a sewer municipally, and obviously in any dense area you want to do it, we need to pay a little more attention if we're going to have a water treatment plant that is going to operate reasonably well. We have to pay more attention to designing our system in such a way that it doesn't have this negative leakage of the ground water into it and the reason they do this is because they don't want any sewage to leak out into the ground so they overdesign to make it leak in. I was an engineer myself once, maybe I still am, but I was always fascinated with these terrific little coefficients that we plugged into our equations, like 2.319. We got our answer and then we doubled it for safety. That's what engineers tend to do and I think anybody who works past the first decimal point is wasting his time and that is a problem. I think we need better design, better engineering.

Comment: I wonder if you feel that protection of ground water is an adequate justification for imposing land use control of various sorts and governing the way that man lives on the surface of the ground and, if so, what your thoughts along that line are as to how it might be done and what the mechanisms and various considerations are.

Dr. Lehr: That's a big question. The answer to the first one is yes, I do believe that protection of ground water is a reason to impose land use control, no matter how severe the political problem. That is to say, I don't like to offend people's rights too much, but I do believe in preserving the land, the greatest good for the greatest many, that can be done in a non-bureaucratic way, so I think that it takes considerable care and thought.

We're doing a little bit of this in our document on developing regulations for the protection of ground water. I really can't be specific about it other than I think it definitely can be used as a reason for land use regulation and maybe as ground water becomes more popular we'll put some emphasis on it and maybe get the Land Use Bill through the Congress next time with this added reasoning. But I could not, in the time or even just off the top of my head, give you any very terrific specifics as to what can be done. Obviously, whether or not you can use septic tanks depends on a land use concept.

Another land use problem works as follows: if you allow uncontrolled building of parking lots, driveways, and shopping centers, you absolutely eliminate ground water recharge; the water all flows out in the stream and if you're using ground water you're depleting your available ground water from a quantity standpoint. This is a serious problem.

PHYSICAL INTEGRITY

THE EFFECT OF HYDROLOGY AND HYDROGRAPHY ON WATER QUALITY

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The Water Pollution Control Act of 1972 addresses issues relating to the development and dissemination of information on the factors necessary to restore and maintain the physical, chemical, and biological integrity of natural water systems, to protect fish and wildlife, and to allow for recreational activities. This paper is directed to the first of these issues and specifically to the hydrologic and hydrodynamic effects on the physical, chemical, and biological constituents of natural water systems. In order to develop information on the factors necessary to maintain and restore appropriate levels of water quality, one of the key elements is our understanding of the effect that manmade and natural inputs have on the quality of these systems. Accordingly, a brief description of the techniques that are available to quantify these effects is first presented, followed by a number of applications to the analyses of quality in various water bodies.

The general purpose of this paper is to indicate how these techniques permit projections to be made for a variety of remedial policies. The ability to project future water quality conditions provides one of many essential elements required for environmental planning. The value of these models can only be appreciated if their weaknesses, as well as their strengths, are understood; accordingly, the limitations of this type of analysis are also discussed. In conclusion, a few observations are made concerning the nature and validity of the analyses and recommendations are presented concerning the direction and needs of environmental planning for water quality.

INPUTS AND WATER QUALITY RESPONSES

Mathematical analyses of water quality are based on quantitative relationships between inputs to natural systems and the water quality responses of the systems.

The common basis of the majority of these models is the principle of continuity or mass balance. This principle is not only of fundamental importance in that it provides a means of structuring realistic models, but is also of practical value in that it establishes a basis for evaluating their validity. Given a water quality problem in a specific area, the particular constituents which relate to that problem are defined. A mass balance is developed for one or more of these interrelated constituents in the water body which takes into account three factors: the transport through the system, the reactions within it, and the inputs into it. The first factor describes the hydrologic and hydrodynamic regime of the water system; the second, the biological, chemical, and physical reactions which affect the water quality constituent; and the third, the inputs or withdrawals of the substances through man's activities and natural phenomena.

Each region or specific site has its own geomorphological structure and hydrometeorological regime which establishes the transport structure. Identification and definition of the particular water quality problem and the related constituents lead to a specification of the reactions which are relevant to that problem. Each region is affected in varying degrees by municipal, industrial, agricultural, and natural inputs which are discharged as either point or distributed sources. Each area thus has a set of specific characteristics which qualitatively describe the problem and which may be expressed quantitatively as transport, reaction, and input coefficients. The transition from the general qualitative principle to a specific quantitative form is determined by assigning a set of realistic coefficients. That they are realistic is determined by the degree to which the concentration, as computed by the model, agrees with observed data for various flow, temperature, and input conditions. This procedure, which establishes the validity of the model, is an important criterion in the assessment.

MODELING FRAMEWORK

The procedure of developing the model to analyze a specific water quality problem consists of three distinct steps: (1) the formulation of the pertinent equations; (2) the selection of the appropriate computational techniques to solve these equations; (3) the application of the equations and their solutions to a particular water system. Although the term "model" is loosely applied to any one of the three steps, it is used inclusively in this paper.

In the first step, the general principle of the conservation of mass, as described above, is used to formulate the equations of the various constituents of water quality. In their simplest form, the equations describe the distribution of conservative substances such as dissolved solids, or singular reactants such as coliform bacteria. They increase in complexity as consecutive reactions (e.g., dissolved oxygen) are addressed. In their most complex form they incorporate the interaction of a number of constituents (e.g., eutrophication and food-chain analysis). For many of the pertinent water quality parameters they are reasonably well formulated at the present time. These relationships have been in a state of continuous development over the past few decades.

In addition to the terms which define the reaction kinetics, the transport factors must also be included. Depending on the geomorphological and hydrological characteristics of the water system the transport may be incorporated in a rather simple fashion or in a relatively complex manner. The degree of simplicity or complexity is predicated on the temporal and spatial variation of the particular substance which is under consideration. The simplest framework is the steady-state, one dimensional analysis, while the most complex relate to time variable analysis in multidimensional space. The latter frequently require the use of hydrodynamic relationships in order to quantify the transport terms of the equation. The wastewater inputs are next considered in the formulation of the pertinent equations. The inputs of mass to the water system are due to the discharges from municipal, industrial, and agricultural activities and the runoff from these areas and from the natural drainage of undisturbed regions. The inputs of various constituents from municipal sources are well known with respect to both the average values and their variations. This assessment is also applicable to many industries which are characterized by the production of one or a few products such as the pulp and paper, canning, and steel industries. However, industries which produce a variety of products such as organics, synthetic chemicals, and pharmaceuticals are more difficult to characterize. The quantitative assessment of the inputs is critical, particularly with respect to the delineation between point sources which are readily controllable and nonpoint sources which are relatively difficult and, in some cases, impossible to control. Water quality responses due to each of these sources must be clearly distinguished and described. The difficulty of assigning realistic values to distributed nonpoint sources is very evident, given the present state of knowledge and data.

The second step consists of seeking the most appropriate method of solution of the pertinent equations. There are two general classes of solutions: one is based on the formal integrations of the basic equations and the second is based on finite difference approximations of the differentials. For the simple and intermediate kinetic reactions under steady-state conditions, the first type of solution is commonly used. For the more complex kinetic and transport regimes, it is usually necessary to employ the second. In either case, there are a number of computer programs for both classes which are available for immediate application.

The last step consists of structuring the solutions, through the programs, to fit the conditions of a specific water system. This step invariably involves a segmentation of the particular water body taking into account the transport, reactions, and inputs. It should allow for a realistic portrayal of the advective and dispersive components of the transport. It should permit a reasonable representation of the kinetics, particularly with respect to geophysical and hydraulic characteristics of the system. Finally, it should provide for a description of the waste inputs and tributaries, both point and distributed. The guidelines for segmentation are also dictated by the method of solution, i.e., analytical integrated forms or finite difference techniques. Given the method of solution, the system is segmented such that the basic assumptions or postulates are maintained without violating certain mathematical or numerical requirements or introducing unnecessary computational complexity.

VALIDATION

The process of validation involves comparison between computed values of a variable and those measured in the prototype. When this comparison is satisfactory, the model is said to be validated. What constitutes "satisfactory" depends on the nature of the problem, the structure of the model, and the extent of available data.

Water quality models, on the whole, are planning and analytical tools rather than predictive and forecasting techniques. The model is used primarily to examine the spectrum of responses of the system which may occur under varying planning alternatives, e.g., the water quality responses for the 1977 and 1983 treatment scenarios under various hydrological regimes.

The first step in the validation of the model is its calibration. Given the geophysical and hydrological characteristics of the system and a water quality constituent whose reactions are known in principle, an estimate or assignment is made of the appropriate coefficients and inputs. These may be known from auxiliary models, as in the case of the hydrodynamic transport terms; they may be assigned from correlations developed in laboratory or field experiments as in the case of the kinetic terms; or they may be specifically measured as in the case of inputs. Transport and kinetic coefficients may also be available from direct prototype observations and measurements. In any case, assuming a range of these values is known, a best estimate is made of each, the model is run, and the output compared to the data. Invariably, successive adjustments are required to obtain a "reasonable" agreement between the model and the data. Having thus calibrated the model, it is then validated by repeating the procedure for a different set of flow, temperature, and input with the coefficients systematically redefined to reflect these conditions. The repetition of this procedure for other combinations effects a greater degree of validation with each favorable comparison between computation and observation.

PROJECTIONS AND PLANNING

The validated models are then used to project water quality conditions for various control procedures or policies. These projections are made for various combinations of hydrological and meteorological conditions for the immediate and long term development of the area. The validated model permits a range of alternates to be evaluated in a realistic and quantitative manner. These projections provide one of the many inputs which the administrator needs in order to make appropriate decisions for environmental planning. The significance of the water quality problem and the consequences of the decision should be examined from both the environmental and economic points of view. The degree to which the analyses, provided by the models, affects the decisions should be commensurate with the level of validity of the models themselves. From the scientific and engineering points of view, the models should be completely verified before they are applied in any practical manner.

EXAMPLES AND APPLICATIONS

The following examples describe the water quality problems in various types of natural water systems, freshwater streams, saline estuaries, lakes and the nearshore oceans. This four-way classification is based on the commonality of geomorphological structure and hydrological and hydrodynamic regimes within each category. The dilution and transport associated with these factors determine in large measure the concentration of constituents which characterize the water quality problems. The problems, actual or potential, are caused by constituents in the water which are conservative and non-conservative. The concentration of non-conservative substances is affected by biological, chemical, or physical reactions, while the concentration of conservative substances is unaffected by such reactions. Each of these constituents is present in water systems due to both natural phenomena and man's urban, agricultural, and industrial activities. In assessing what remedial measures must be taken to restore water quality, one of the most important considerations is the distinction between natural and manmade effects. Within each category, the further distinction should be made between readily controllable point sources and the more difficult distributed sources.

The first example concerns the buildup of total dissolved solids and chlorides in the Great Lakes. Since they are conservative and not affected by settling or volatilization, their concentrations are determined only by the dilution and transport due to the freshwater flow through the systems. The pertinent transport parameter is the hydraulic detention time, which is the volume of a lake divided by the total flow through it. A map of the Great Lakes and their drainage areas is presented in Figure 1 which indicates the relative magnitude of each lake and the direction of transport. The source of freshwater flow through Lakes Superior and Michigan is the cumulative runoff of the rivers draining into each. Their combined discharge flows through each downstream lake in sequence—Huron, Erie, and Ontario, each of which receives additional drainage from its tributary streams.

The water flow through each lake also provides dilution for the inputs of chlorides and dissolved solids, whose sources are municipal and industrial wastewaters as well as the deicing salt contained in runoff from highways. The municipal and industrial sources have been increasing markedly since the turn of the century, as shown by the growth of population and of the industrial chemical index in Figure 2. The use of salt for deicing purposes was initiated in the 1930's. The increase in concentration due to these sources is added to the natural background value, which is assumed to be in equilibrium. The combined effect of all the sources on the concentration of chlorides from 1900 to 1960 in each lake is shown in Figure 3—the solid line representing the calculated value and the circles representing the observations. The marked increase in Erie and Ontario is contrasted to the slight increases in Michigan and Huron and the constancy in Lake Superior. These patterns are due to the relatively rapid growth of population and industry in downstream drainage areas by contrast to the moderate growth in the upstream areas. A further significant factor is the hydraulic detention times—approximately 3 and 8 years for Erie and Ontario, respectively, and over 100 years for Lake Superior. Thus Lake Erie responds more rapidly due to its larger municipal and industrial inputs and smaller hydraulic detention time. These factors are also responsible for the greater rate of eutrophication in this lake.

It is informative to examine the relative influence of each of the components which make up the chloride concentration. Figure 4 indicates the contribution of each source to the total concentration in Lakes Erie and Ontario. The greatest impact in Lake Erie is due to the industrial discharges. Municipal sources are fairly significant while the deicing salt is becoming more pronounced as time goes on. The effect of the upstream input from Lake Huron is also important. In Lake Ontario, however, the greatest effect is felt by the Lake Erie inflow. While the combined effect of the municipal, industrial, and deicing sources is significant, it is obviously much less than that of the Erie input.

A similar analysis was made for the concentration of total dissolved solids and the patterns were substantially identical. An example of the application of this type of analysis is presented in Figure 5. If both industrial and population growth and the increase in deicing salt usage were to continue at the rates experienced in the past, the total dissolved solids would reach a concentration of 500 mg/l about the year 2050. This is shown by the upper line in Figure 5. If industries in the Ontario basin ceased discharging salts, there would be an initial decrease; but as the population grew the trend would be reversed and the solids would again increase. This simple example is presented to demonstrate the utility of the analysis in environmental planning and management.

The Ohio River below the city of Cincinnati, as shown in Figure 6, is subjected to a backwater effect from the Markland Dam. Prior to its construction, there were five individual dams, whose reservoirs had shallower depths and smaller cross sectional areas, as shown in the lower right-hand corner of Figure 6. The height of the Markland Dam submerged the existing dams, creating a water depth in the order of 100 feet at its face which decreased in the upstream direction. The cross sectional area of the river varies in a similar fashion, as shown in Figure 7. The larger cross sectional area reduces the time of passage through the system and the greater depths markedly change the reaeration capacity of the water body. The effluent from the sewage treatment plant serving the city of Cincinnati was the primary source of wastewater. The effect of this effluent on the dissolved oxygen concentration is shown in Figure 8. The solid line is that calculated by the model and the various symbols represent observations taken during periods when the river flow and temperature were the same. There is a very rapid drop followed by a relatively slow buildup. This pattern is primarily due to the increasing depth of the body of water which affects its gas transfer characteristics. As the depth increases, the ability to transfer oxygen from the atmosphere to the system decreases and, consequently, the DO is depressed and remains so for a significant number of miles downstream.

The projections are shown in Figure 9. The components of the dissolved oxygen deficit are shown in the upper figure and the resulting dissolved oxygen profiles in the lower. The flow of approximately 10,000 cubic feet per second is a relatively low flow for the Ohio River. Even with high degrees of treatment, such as 90 percent removal of the carbonaceous demand and 80 percent removal of nitrogenous demand (the order of best practical treatment), the resulting profile indicates a minimum concentration of about 3.5 mg/l. A projection back to hydrographic conditions of the lower dams would indicate that the dissolved oxygen would be in the order of 2 mg/l greater. The hydrographic and hydraulic effects caused by the construction of dams may be quite significant and presently available methods of analysis permit this assessment to be made as demonstrated by this example.

The river flow of 10,000 cubic feet per second, which is a low flow for the Ohio River used in the previous example, is significantly greater than that available in other geographical regions of the country. The effect of river flow is further evidenced in those areas where large metropolitan developments are located on upstream tributary streams of larger river systems. The effluent flow may be greater than the flow in the river, as in the case of Atlanta, Ga., and Dallas, Tex. It is frequently of the same order as in Denver, Colo., and the Rome-Utica area in New York. For example, the Rome-Utica metropolitan districts are located in the upstream region of the Mohawk River Basin, as shown in Figure 10. The drainage areas and flows are presented in Figure 11. The wastewater inputs, as measured by the present and projected carbonaceous oxygen demand (BOD) and a typical dissolved oxygen profile during September 1966, are plotted in Figure 12. The concentration frequently drops to zero during the summer months when the temperature is high and the flow low. The computed profiles and observed data of both BOD and DO are shown in Figure 13 for July 26, 1967. This, in conjunction with analyses of other survey periods, indicates substantial agreement between calculation and observation.

The components of the dissolved oxygen analysis are plotted in Figure 14. The sum of the individual elements is shown in the upper segment of this figure, which is subtracted from the dissolved oxygen saturation value to yield the calculated profile of Figure 13. Breaking down the problem to its individual elements enables an evaluation to be made of the effective methods of control. The carbonaceous and nitrogenous deficits are caused by the Rome and Utica wastewaters, while the sludge deposits are primarily the result of storm drainage. The background values are shown in the lower portion of Figure 14.

Water quality projections for future levels of development of the area were made, utilizing the validated model as shown in Figure 15. For each level of projected development, various degrees of treatment were imposed and the resulting dissolved oxygen concentrations determined. It is evident that water quality problems of low oxygen persist for many of the projected conditions. The sharp drop in dissolved oxygen downstream from Rome occurs in a small tributary of the Mohawk. If the outfall is relocated 1 mile downstream to discharge directly to the Mohawk, as shown in Figure 16, the depressed dissolved oxygen in this stretch is eliminated. Knowledge and understanding of the hydrology of the system permits evaluation of alternate methods of control as indicated by this example.

By contrast to freshwater streams, saline estuaries are characterized by different hydraulic and hydrographic features. The primary difference lies in the mixing and dispersion due to the density and tidal effects. The following examples, describing water quality studies in the Houston Ship Channel and New York Harbor, illustrate the importance of these factors. Figure 17 shows a map of the Houston Channel and Galveston Bay which flows to the Gulf of Mexico. The tidal effects in the bay are dampened by the restricted inlet, and hydraulic transport is further affected by the relatively low freshwater flow. Because of these characteristics, substances are retained in this system for extensive periods. A map of the channel is presented in Figure 18, indicating the location of the sampling and gaging stations. Figure 19 portrays the distribution of freshwater flow and the location and magnitude of the wastewater inputs as measured by the biochemical oxygen demand. Figures 20 and 21 present the data and calculation for the dissolved oxygen during the wet and dry periods, respectively. The increase in freshwater flow shown in each drawing is due to the San Jacinto River. The range of the dissolved oxygen values as shown by the bars reflects the difference between the surface and bottom concentrations. It is evident that this system is highly stratified, as is frequently the case in estuaries. The extended region of zero dissolved oxygen is caused by the high waste inputs into tidal systems of low freshwater flow and moderate tidal mixing. Projections of water quality conditions, based on secondary treatment of all the waste sources, is shown in Figure 22. Even with low flow augmentation of 500 and 1,000 cubic feet per second, low dissolved oxygen concentrations persist. The hydraulic influence of the augmented flow is relatively minor because of the large volume of water contained in the manmade channel and turning basin, a large volume at great depth and small velocity.

A further example of the hydrography of a tidal system is New York Harbor, a map of which is shown in Figure 23. The total mass discharge of BOD is much greater than that of the Houston Ship Channel. Dissolved oxygen concentrations, although depressed, are not as low as those in the channel. This is due primarily to the relatively intense mixing and dispersion of the tidal factors in New York Harbor and, to a lesser degree, to the effect of the Hudson River freshwater flow. At the time the analysis was performed the crosshatched areas of New York City, as shown in Figure 23, were not receiving sewage treatment. Since that time treatment plants have been installed in these areas except for the western part of Manhattan Island on the Hudson River, which is presently under construction. Figure 24 shows the comparison between the model and the data for the Hudson River and the East River. With projections of secondary treatment in the order of 65 to 85 percent removal of the significant waste sources, the DO can be increased to about 4.5 mg/l in the North River and 3.5 mg/l in the East River. The DO has never dropped below about 1 mg/l in the East River or below 2 mg/l in the Hudson River even when the waste discharge was greater than that shown in the figure. The primary reason is the maintenance of dissolved oxygen due to the rather intense tidal mixing and freshwater flow which permits this particular system to respond much more positively to pollutional stress.

The nearshore ocean regimes also involve hydrologic and hydrographic factors. A prime example is the Boston Harbor area shown in Figure 25. The problem was the bacterial pollution which prevailed throughout the whole system which necessitated closing the bathing beaches and the shellfish areas. The major sources of pollution were the effluents from two treatment plants at Nut Island and Deer Island, the storm overflows from the Charles River and the discharge of sludge from the treatment plants. The significant hydrodynamic phenomenon is the dispersion due to the tidal and density effects which transports material laterally and longitudinally in the horizontal plane of the harbor. Figure 26 presents the 1967 calculated and observed distribution of coliform bacteria which indicates fairly good agreement. In the interval between 1967 and 1969 the construction of the Deer Island plant was completed and chlorination was put into operation. In 1969, then, the system received the chlorinated effluent from Deer Island, the storm overflows from the Charles River, and the sludge discharge from the plants. Figure 27 shows the 1969 coliform distribution. The calculated concentration south of Deer Island can be interpolated to be about 2,000 MPN/100 ml by contrast to the 120,000 MPN measured in 1967. The individual effects of the waste input components are shown in the following figures. Figure 28 shows the computed coliform concentration from the Deer Island and Nut Island chlorinated effluents, which are insignificant. Figure 29 shows effects of the discharge from the storm overflows from the Charles River area. The value south of Deer Island can be interpolated at about 800 MPN/100 ml. Figure 30 shows the effects of sludge disposal practice resulting in a level of almost 1,000 MPN/100 ml.

The superposition of these three inputs yields the total of about 1,800, which is in reasonable agreement with the observation. It is apparent that the sludge disposal and the storm overflows are causing a higher level of pollution to the system than are the treatment plant discharges. It is obvious then that alternatives other than treatment of point sources can be evaluated and analyzed. Such alternates may provide more effective improvement in water quality than advanced levels of treatment from point sources.

Another nearshore ocean example is the New York Bight. The area is presently used for disposal of sewage sludge, dredge spoil, construction debris, acid waste, and toxic chemicals from the metropolitan area. Figure 31 shows some of the sites and quantities involved both in New York waters and Long Island Sound waters. Figures 32 and 33 show the results of drifter studies in the bight area, which qualitatively indicate the hydrology and hydrography of the area. Surface drifters were translated to the Long Island shore, some to the Jersey shore, and some out to sea. Most significant is predominance of the bottom drifters which moved with the bottom currents to the Long Island shore. These simple yet informative field experiments which were conducted by NOAA are indicative of the complexity of the hydrodynamic regime, which is affected by tides, freshwater flow from the lower harbor, winds, and density effects. Due to the currents and dispersion associated with the hydrodynamic and hydrologic regimes of the region, the sediments are being slowly transported northward toward the Long Island shore. Furthermore, in the immediate vicinity of the disposal sites, depression of dissolved oxygen is occurring as shown in middle and lower segments of Figure 34. Figure 31 also indicates the location of plant outfalls from Long Island: the Nassau County outfall presently under construction, and the proposed Suffolk County outfall.

The solution of the hydrodynamic problem is particularly important, because of the sludge disposal practices, which impact the individual site locations and potentially the shore region. By virtue of the hydrodynamic transport of the system, the organic material is gradually moving shoreward, as more material is added. This pattern is evident in Figure 34, which presents the spatial extent of the organic matter in the sediments.

Studies were made of the individual and combined effects of the outfalls on water quality in the area. An example of this analysis is shown in Figure 35, which presents the projected concentration of nitrogen in both the surface and bottom for the condition of ultimate development of the areas. The composite effect of these outfalls, the Hudson River discharge, the sludge disposal, and the New Jersey outfalls should be analyzed.

The final example relates the process of eutrophication, which is the fertilization of natural water systems, producing excessive amounts of phytoplankton or aquatic weeds. Although lakes are particularly susceptible to this phenomenon, it also occurs in freshwater streams and saline estuaries. The analysis of the problem is straightforward in principle: inorganic nutrients, nitrogen and phosphorus, are converted to plant organic material through photosynthetic action. The plants usually grow during the summer and spring when temperature and light conditions are conducive, die in late fall with little or no growth taking place during the winter. They are also preyed upon by the next link in the food chain—the herbivorous zooplankton—they, in turn, by the carnivores. These are then a food source for the next trophic level and sequentially through the food chain to man. Each trophic level by death and excretion returns organic nutrients which hydrolyze to inorganic forms, and the cycle continues. Controlled discharges of nutrients to natural water systems are incorporated in this natural cycle and may be helpful and beneficial to productivity. It is the excessive discharge of nutrients which causes the degradation of water quality.

In addition to the availability of nutrients, other conditions affect the growth of phytoplankton, one of which is the flow through the system. Reducing the hydraulic transport through the system may increase the severity of the problem by retaining nutrients in the system for greater periods and thus increasing their availability to phytoplankton. One phase of the California Water Plan is potentially faced with this problem. It has been proposed to divert water from the Sacramento River in the north to the relatively arid areas in the south by means of a peripheral canal on the eastern border of the Sacramento - San Joaquin Delta, as shown in Figure 36. The question arises, then, as to what effect the reduced flow through the delta and the downstream Suisun Bay will have on the eutrophication.

Two specific geographical areas are analyzed in order to demonstrate the effect of freshwater flow: one at Mossdale, on the freshwater portion of the San Joaquin, and the second the estuarine area, as shown in Figure 37. The annual variation of temperature, flow, and radiation for the years 1966 and 1967 is presented in Figure 38 for the San Joaquin River. These, in conjunction with the nutrient discharges, were input data for the model which calculates the temporal distribution of phytoplankton, zooplankton, and nutrients. These distributions are presented in Figures 39 and 40 for the freshwater San Joaquin River at Mossdale and for the estuarine waters at Antioch, respectively. The effect of the hydrology is evident; contrast the pronounced bloom in the spring of the low flow year in 1966 to the high flow in 1967, which essentially flushes the system before it has an opportunity to grow. The lower flow at the end of the year permits growth to take place as evidenced by the fall bloom in 1967. In the estuarine area the tidal mixing predominates over the freshwater flow and growth of phytoplankton occurs to about the same degree each year. The effect of freshwater flow in this region is obviously less pronounced.

Although there are differences between the calculated profiles and the observations, the general pattern is reproduced by the model, at least to the degree which permits some preliminary evaluation of the effects of flow diversion and increased discharge of nutrients. The model was run for these projected conditions and the results are shown in Figure 41. It is to be noted that increased nutrients and light have a more pronounced effect than decreased flow. Furthermore, since levels of greater than 100 ug/l of chlorophyll are projected, which are considered excessive, removal of nutrients is called for. The bottom graph in Figure 41 indicates that presently available treatment technology for nutrient removal maintains concentration levels which are considered acceptable.

CONCLUSION

One of the essential elements in developing information on restoring and maintaining water quality is an understanding of the effect that man's activities and natural phenomena have on the quality of water systems. These systems may be characterized in different physical, chemical, and biological ways. This paper has emphasized the effect that the hydrological and hydraulic factors have on water quality, specifically addressing the physiochemical and biochemical phenomena. By virtue of the mass and energy transfers through the pathways associated with these phenomena, organic substances are converted to bacterial cells, consuming oxygen, and inorganic nutrients are utilized by algae, producing oxygen. This conversion, upon which the higher biological forms depend, is an essential link in the food chain.

The term "biological integrity" covers the spectrum from the microscopic bacteria and algae to the fish and microscopic plants. Although there is, in general, greater public awareness about the latter, the former are of more fundamental concern because they form the basis of the food chain. Furthermore, they are of practical importance because water pollution control measures are specifically directed to the removal or transformation of these microscopic substances which, in turn, maintain and/or restore aquatic environments conducive to the preservation of the higher forms.

While the phenomena relating to the microscopic forms have been quantified (albeit with some scientific disagreement), those relative to the higher biological levels have not been—at least not to the point where reliable projections can be made. It is thus possible at the present time to make predictive assessments of dissolved solids, bacteria, dissolved oxygen, nutrients, and phytoplankton, but extremely difficult to make such assessments about fish and aquatic plants. The ability to formulate quantitative relationships decreases progressively as higher levels of the food chain are addressed because of the increased diversity and myriad interactions which characterize these levels. It becomes progressively more difficult as more complex problems are analyzed, e.g., the accumulation of toxic material in the various trophic levels.

Significant advances in our scientific understanding of these phenomena have been made over the past few decades, but not to the point where reliable quantitative assessments can be made. It may be neither possible nor necessary to do so in the immediate future. In some cases, then, the nature of the environmental questions exceeds our present ability to provide reliable answers. Perhaps, at this time, qualitative assessments are sufficient to effect a dramatic improvement in water quality and this appears to be the spirit of the recent legislation. In any case, the analyst has the deep obligation to indicate the extent and degree of validation of the model, such that some measure of its reliability is evident to the administrator in the decision-making process.

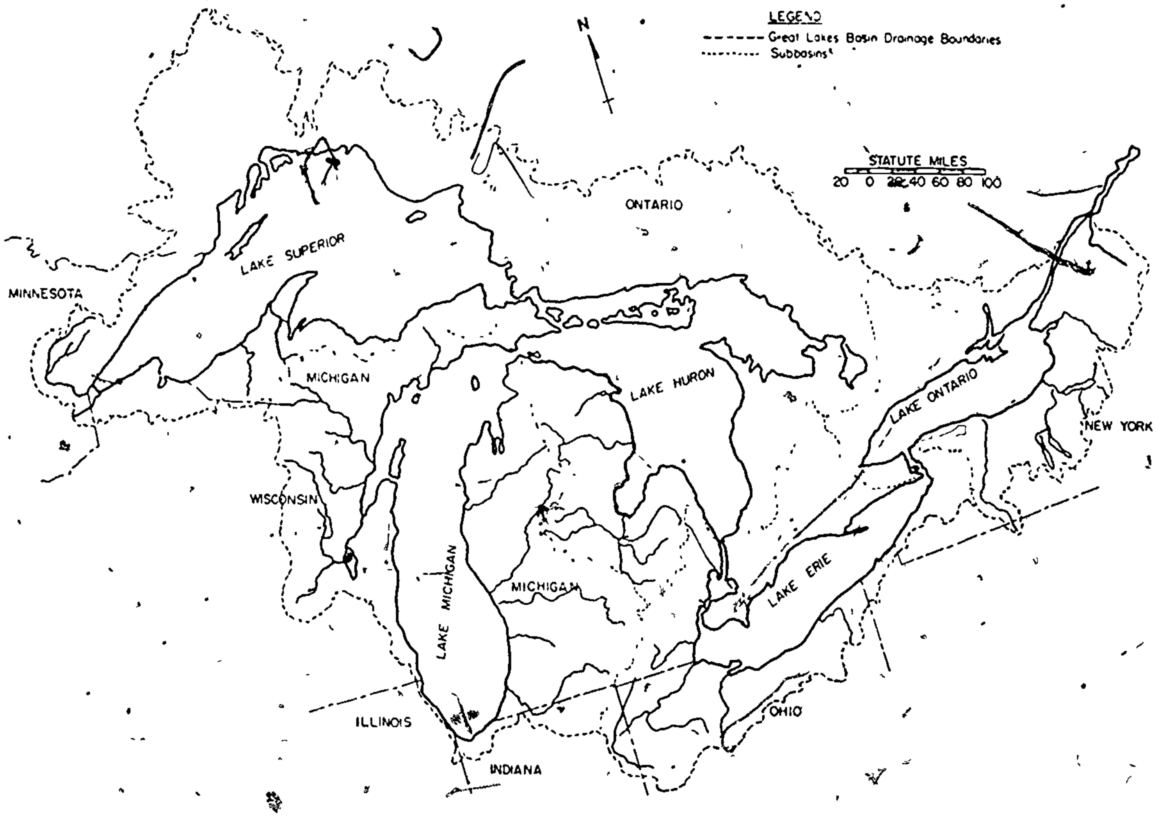
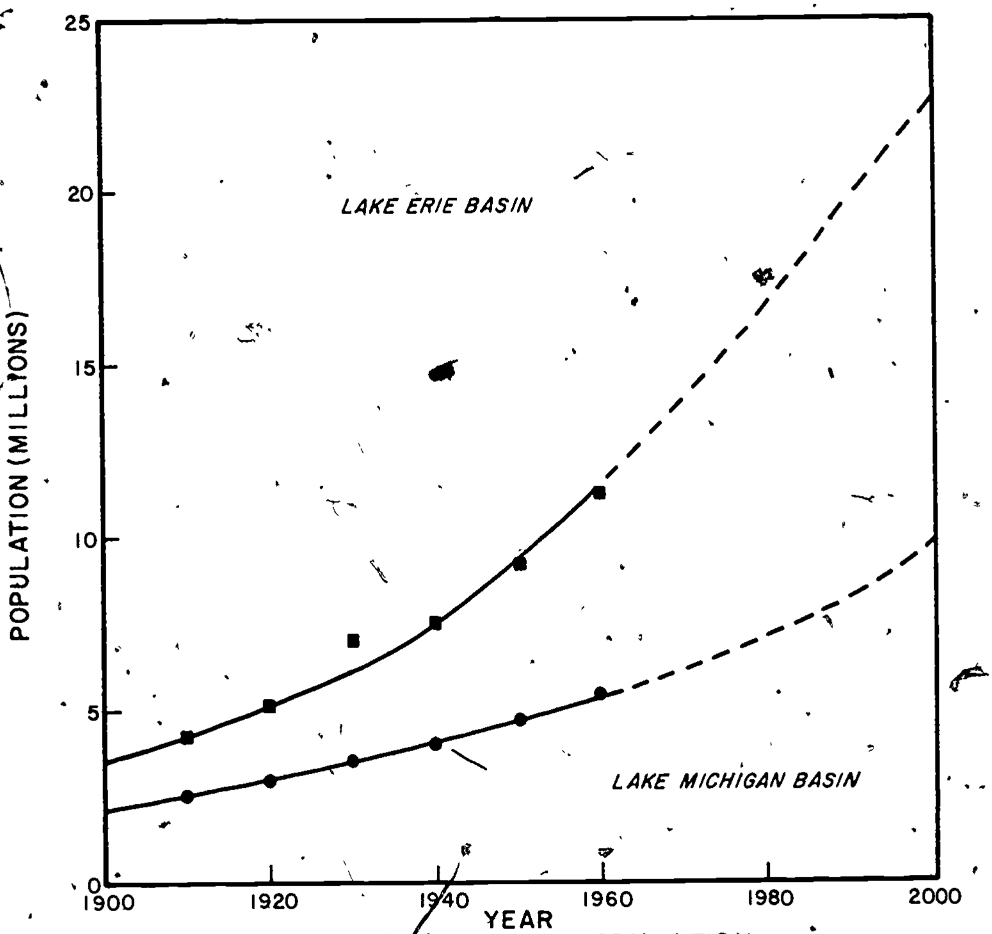
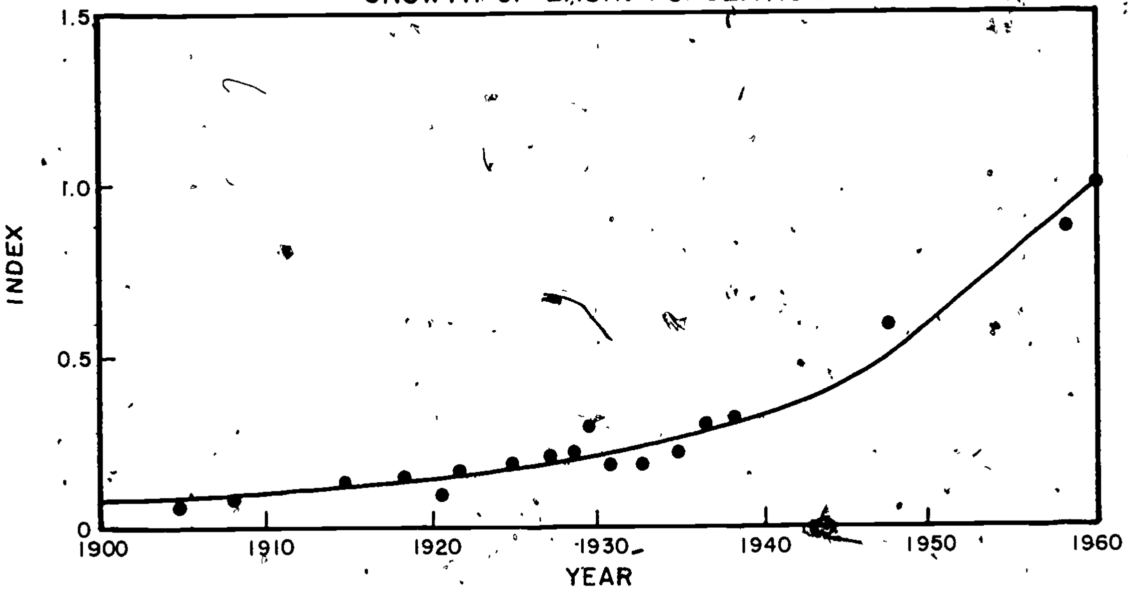


FIGURE 1.—Map of Great Lakes.



GROWTH OF BASIN POPULATION



INDEX OF U.S. CHEMICAL PRODUCTS

FIGURE 2.—Population and industry growths.

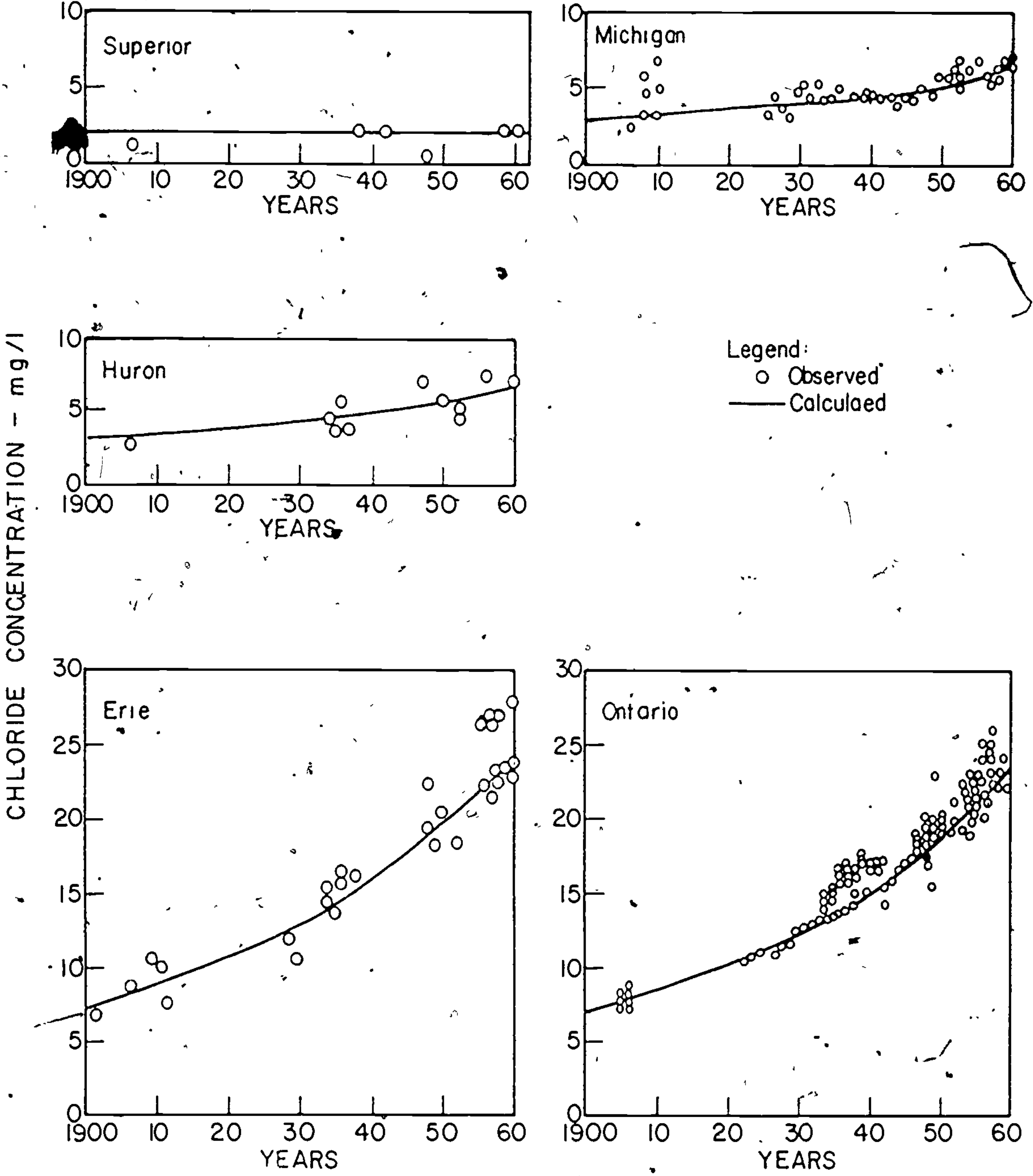


FIGURE 3.—Computed and observed chloride concentrations.

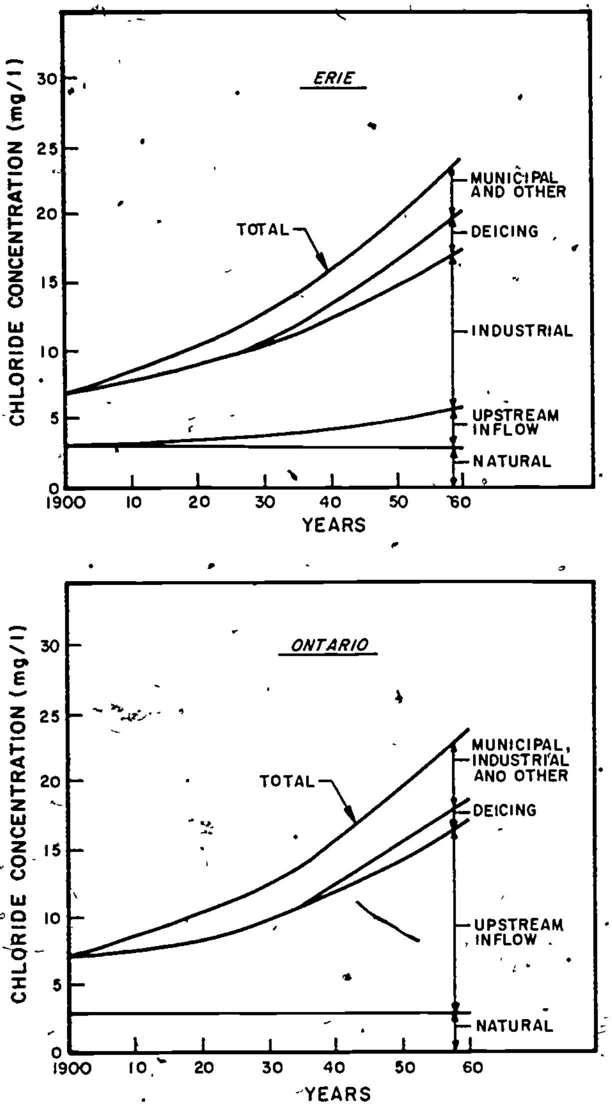


FIGURE 4.—Source chloride components for Lakes Erie and Ontario.

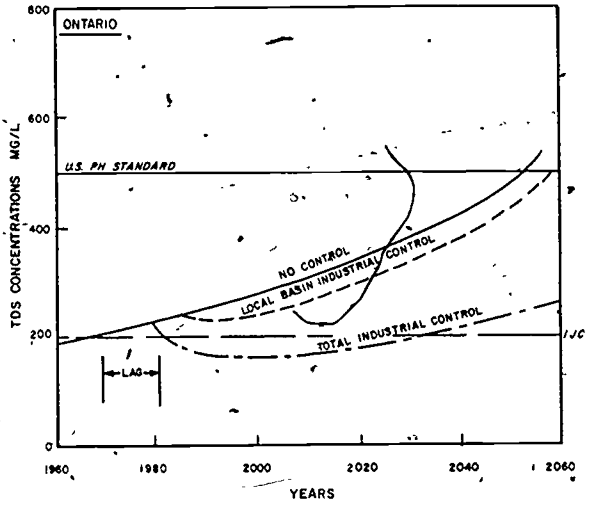


FIGURE 5.—Projected TDS concentrations.

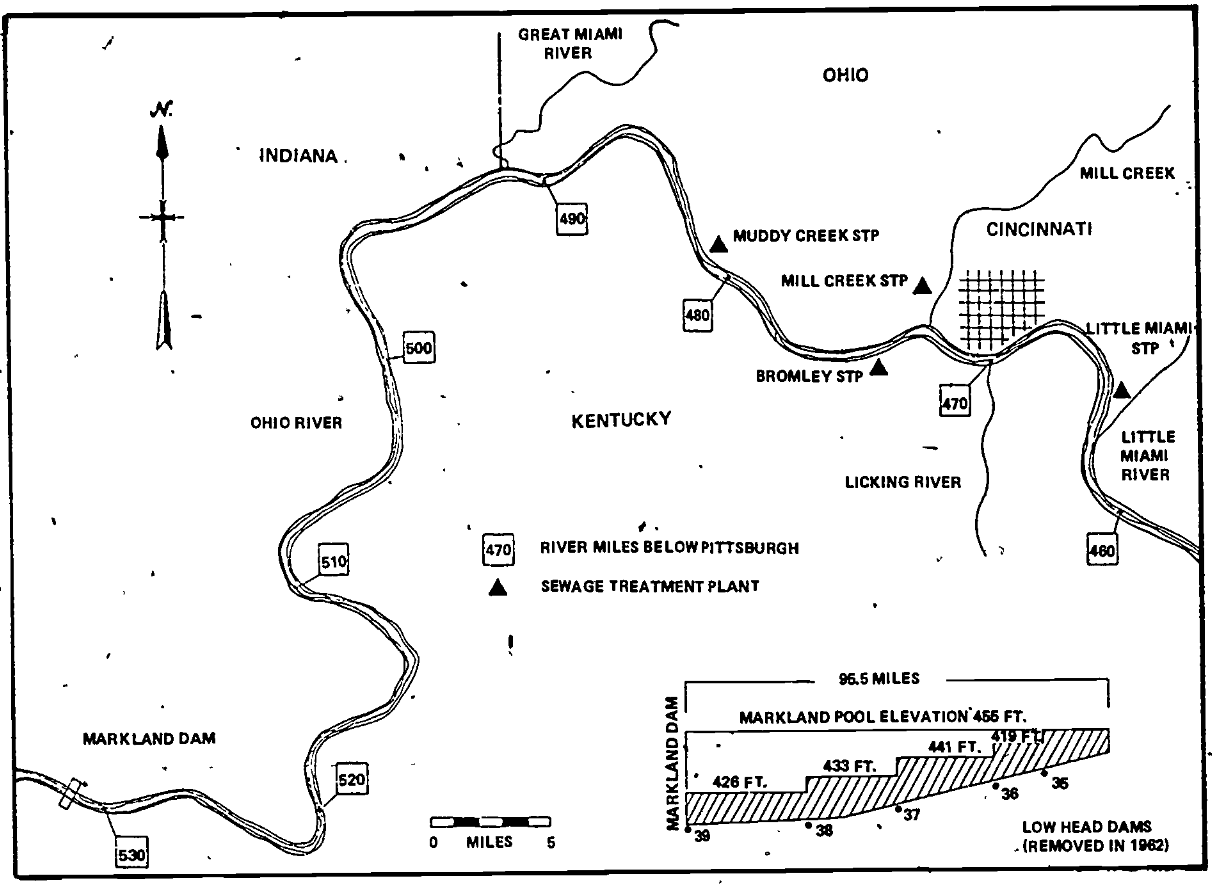


Figure 6.—Map of Ohio River and Cincinnati.

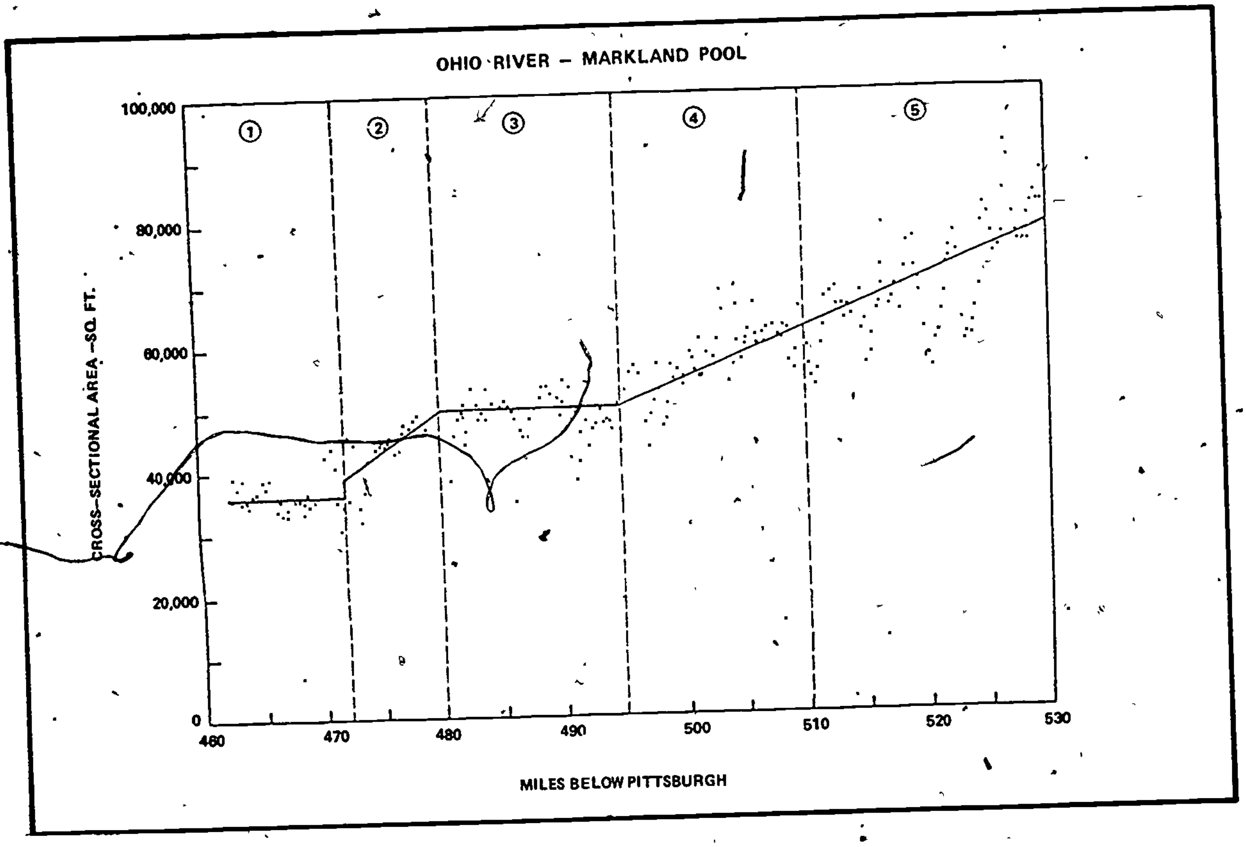


FIGURE 7.—Cross-sectional area in the Markland Pool.

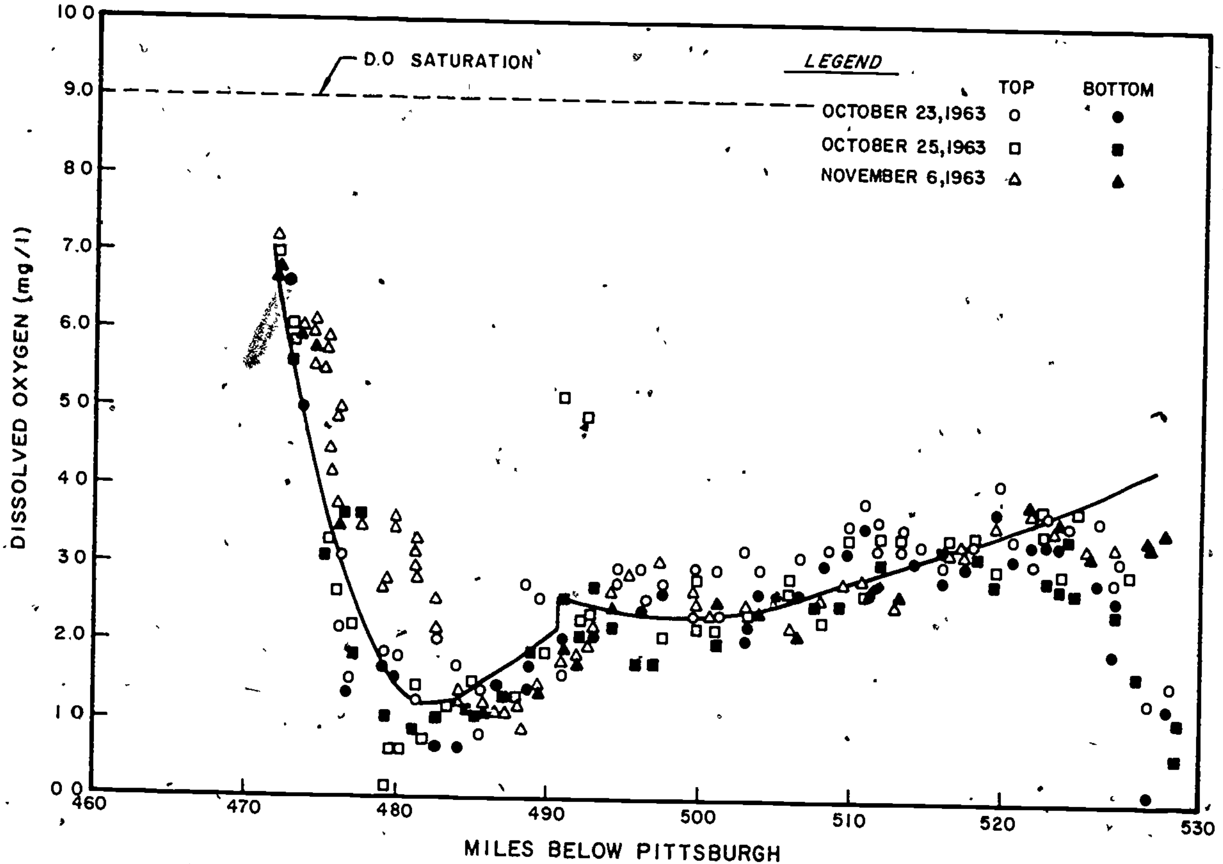


FIGURE 8.—Calculated and observed DO distributions.

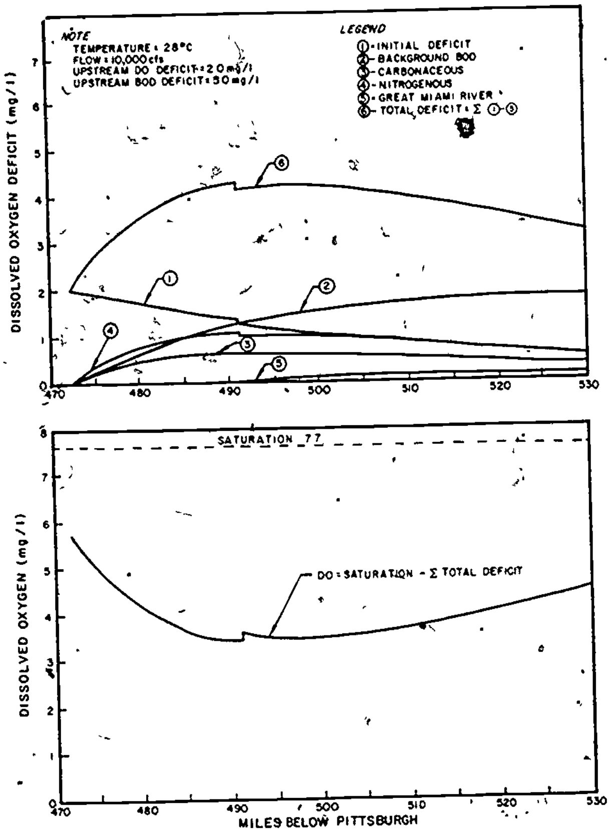


FIGURE 9. — Dissolved oxygen for secondary treatment.

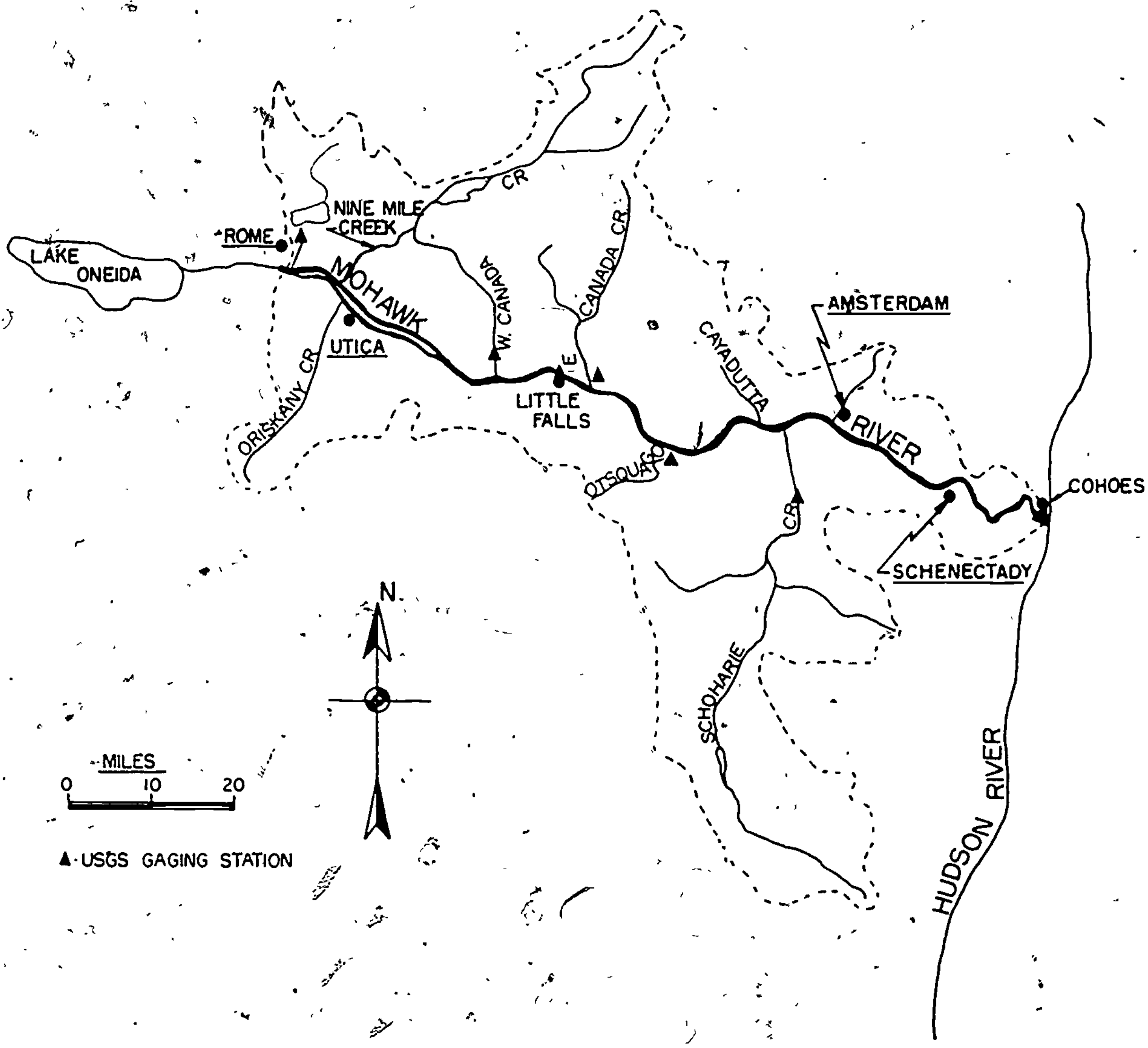


FIGURE 10.—Map of Mohawk River Basin.

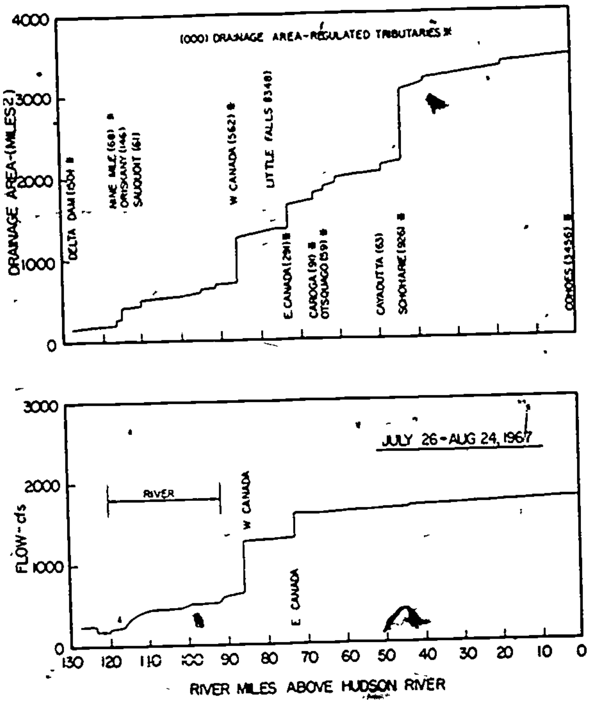


FIGURE 11.—Drainage area—flow distribution.

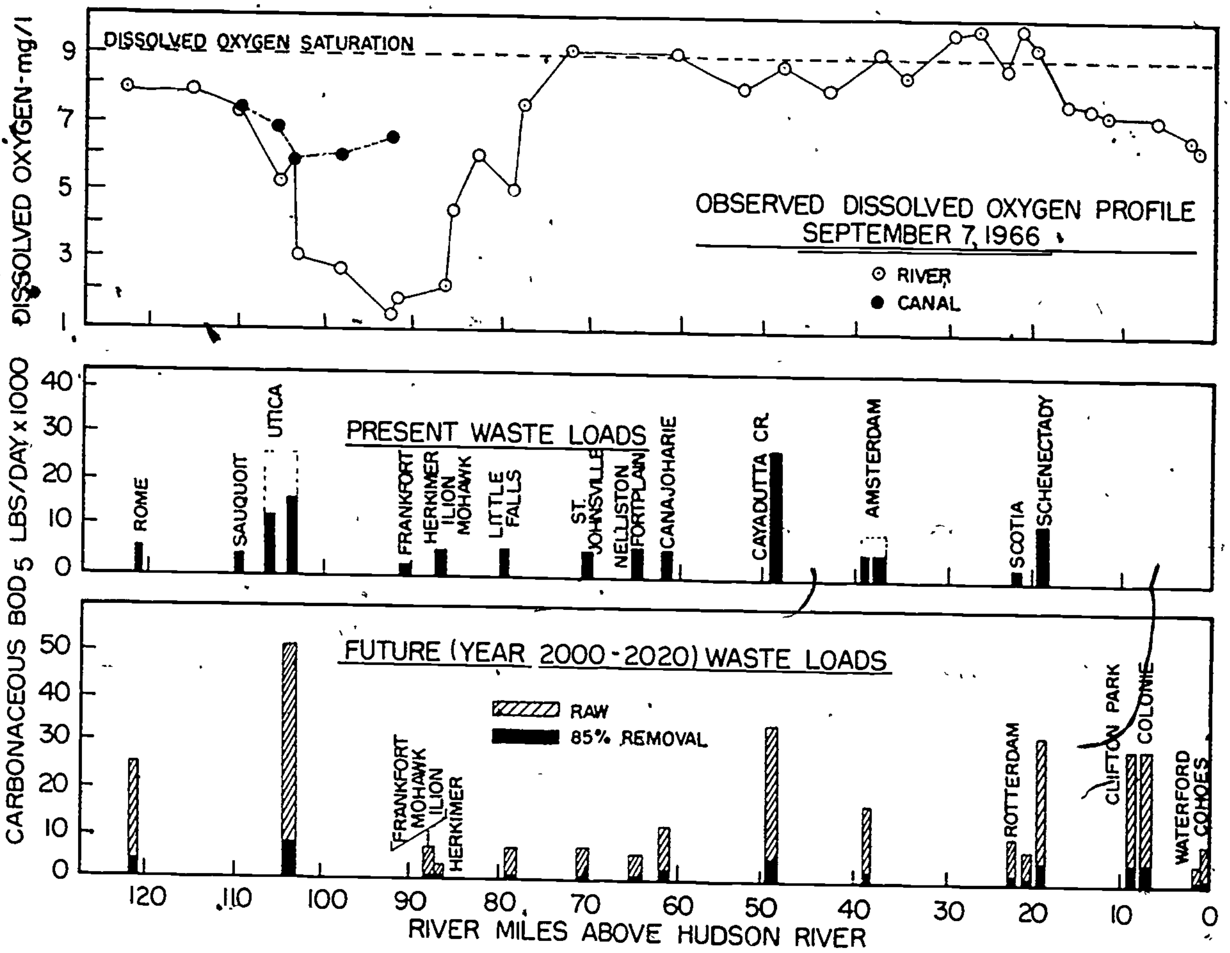


FIGURE 12.—Major waste inputs—observed dissolved oxygen profile.

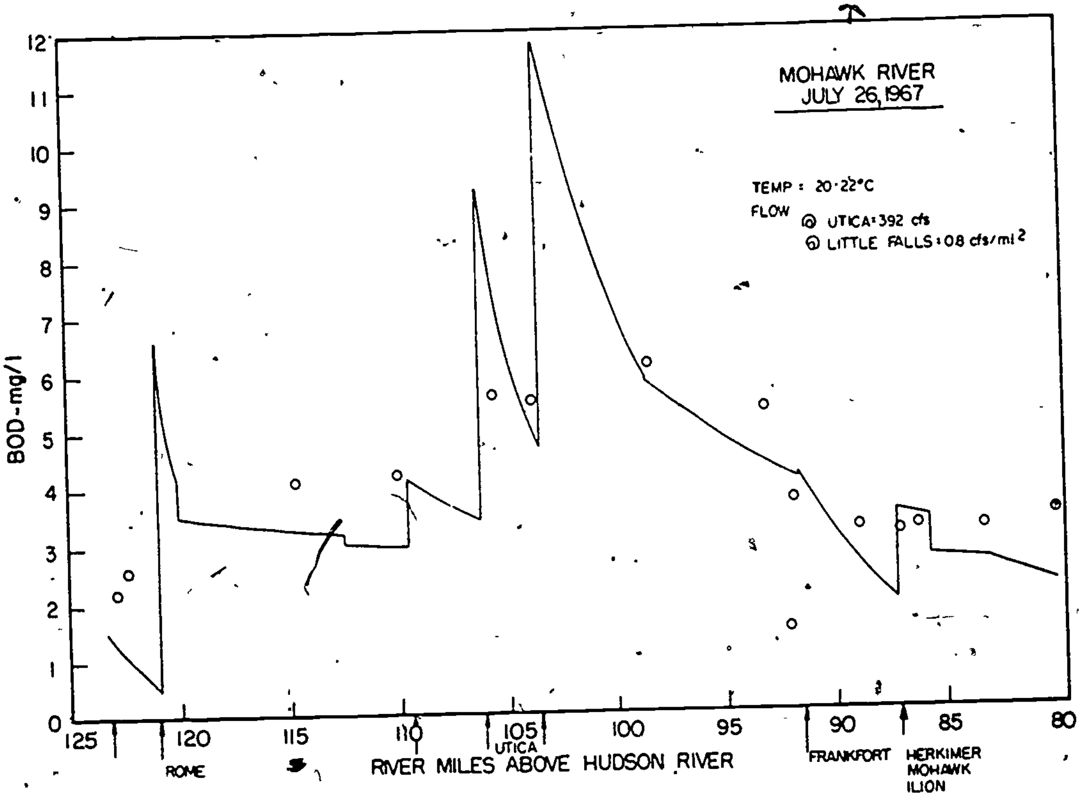
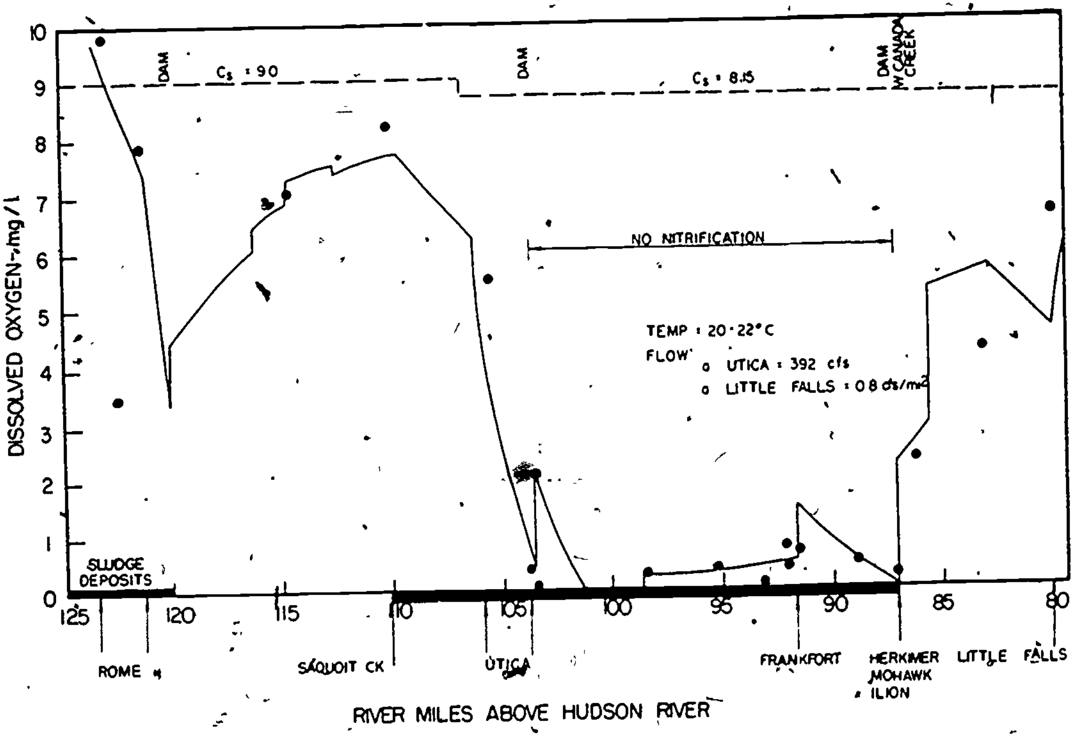


FIGURE 13.—A (top): BOD$_5$ profile, Rome to Little Falls. B (bottom): Dissolved oxygen profile, Rome to Little Falls.



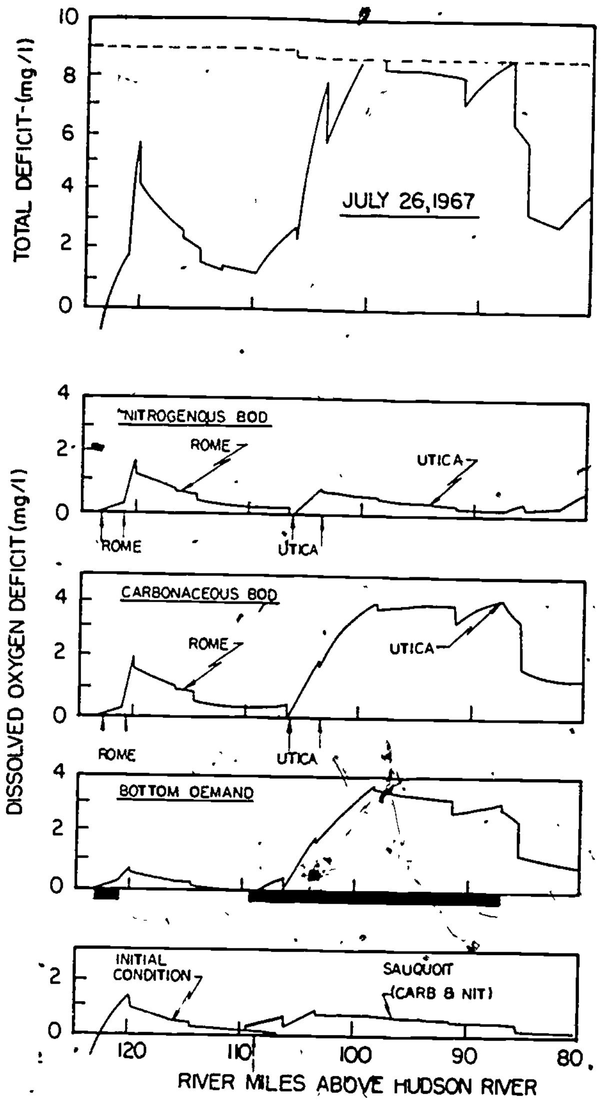


FIGURE 14. — DO deficit distributions for individual components.

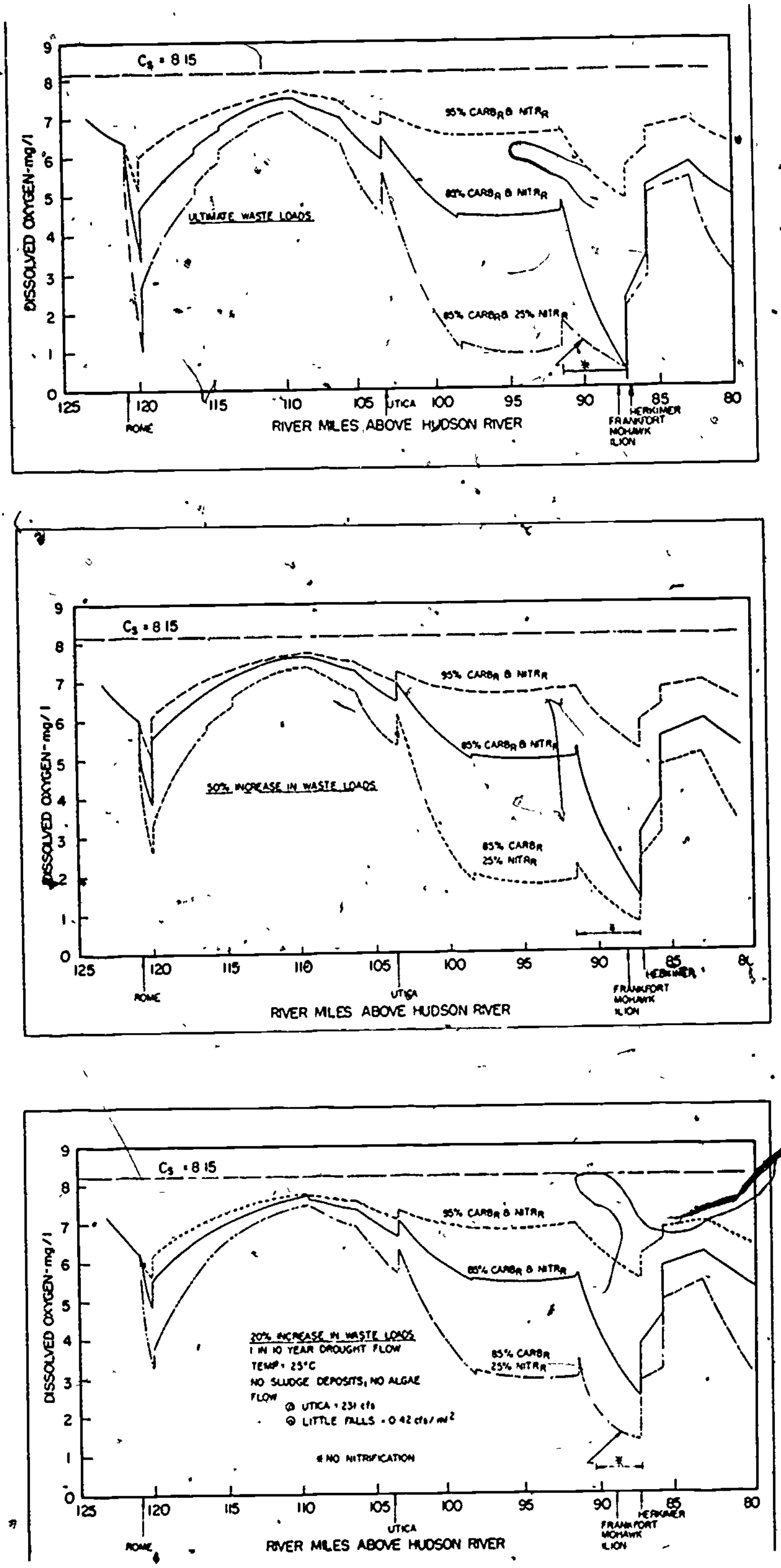


FIGURE 15.—Dissolved oxygen profiles; projected waste treatment—upper Mohawk River.

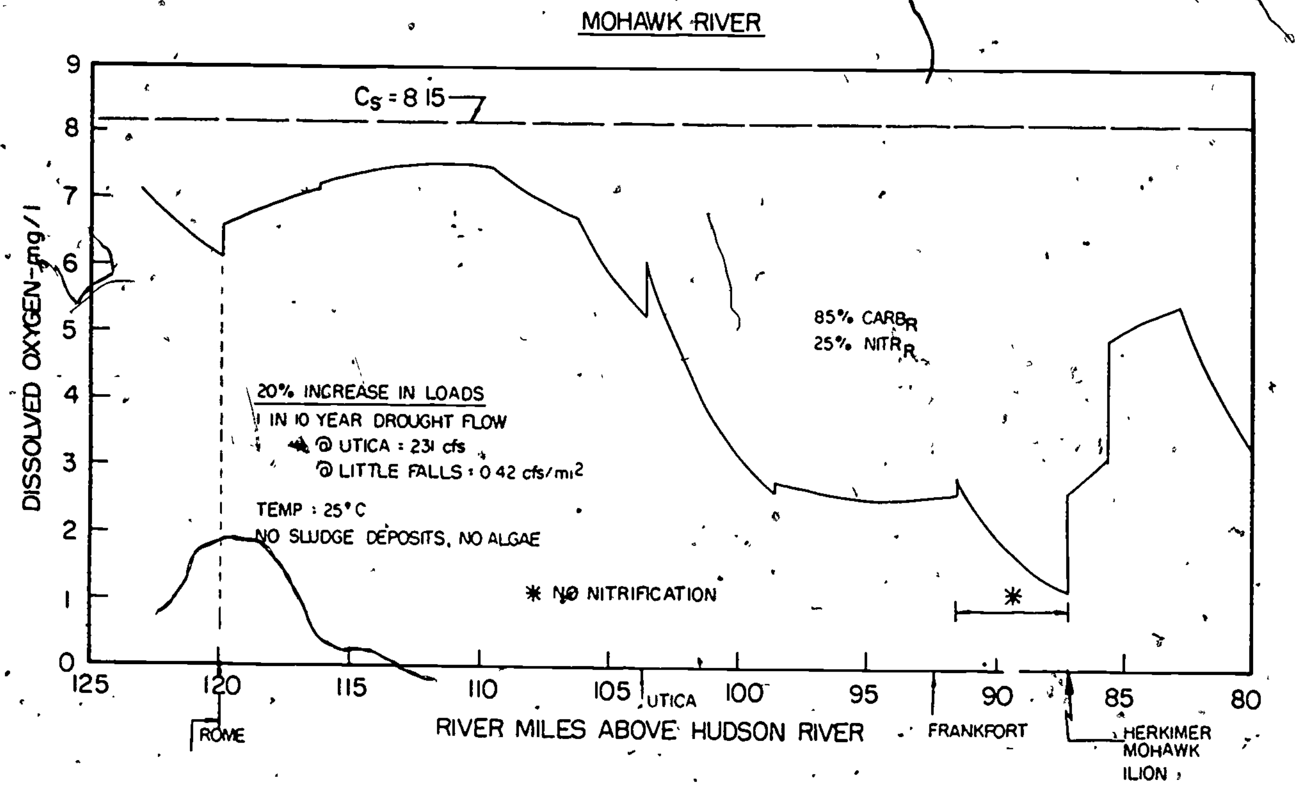


FIGURE 16.—Dissolved oxygen profile, Rome outfall relocated at miles point 120.

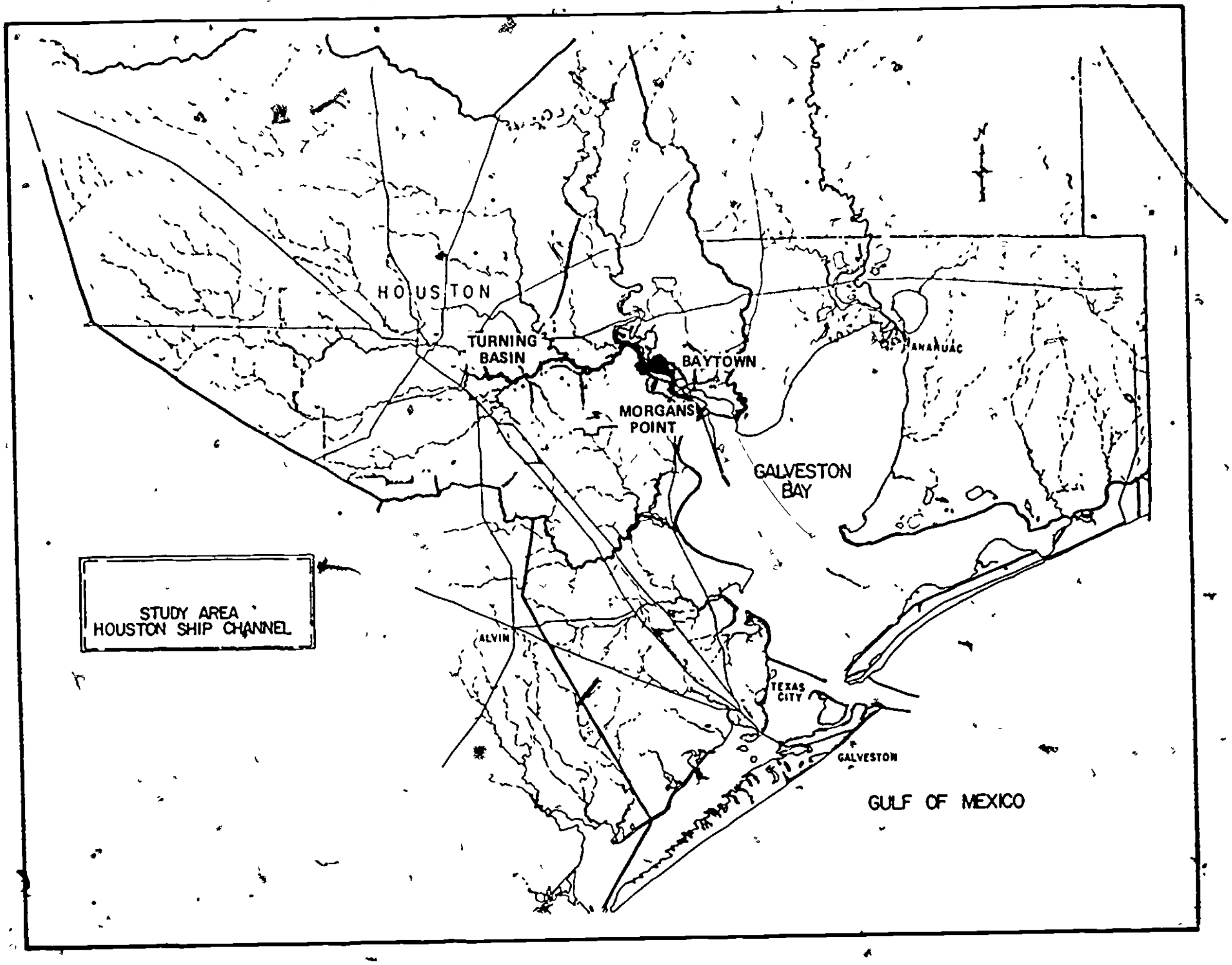


FIGURE 17.—Map of Houston Ship Channel and Galveston Bay.

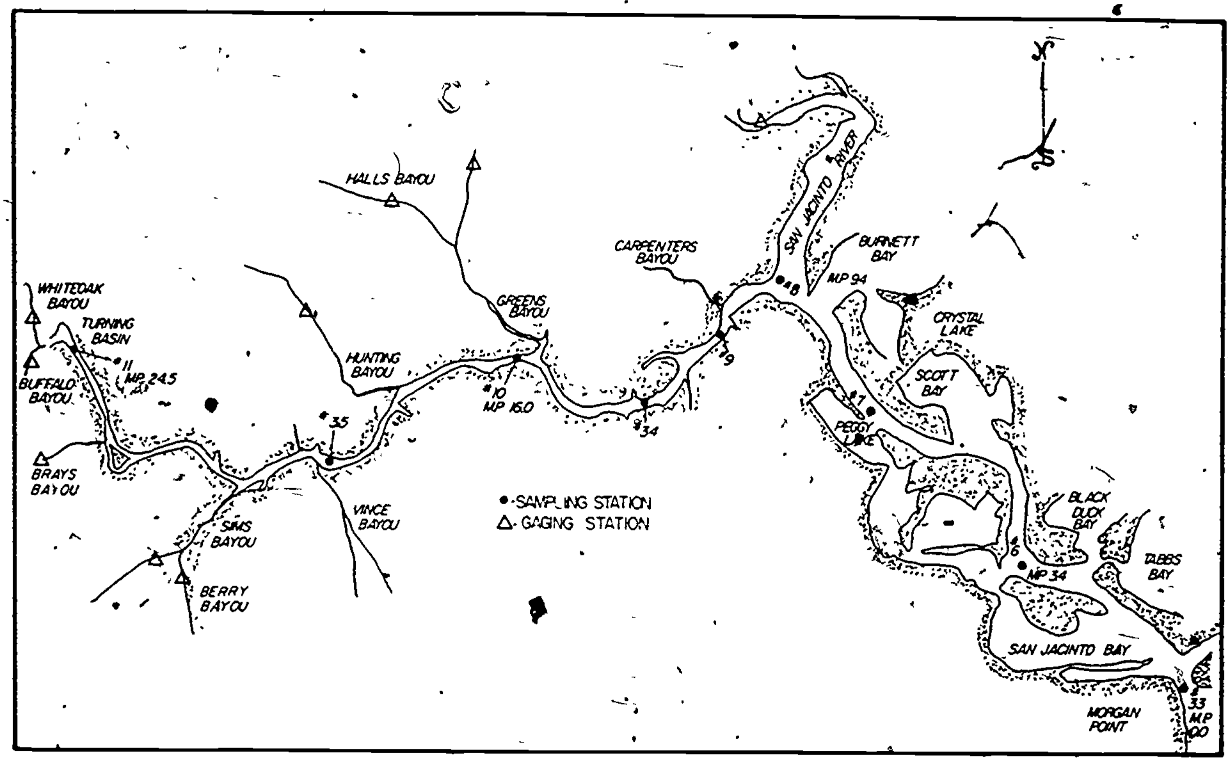


FIGURE 18.—Map of Houston Ship Channel.

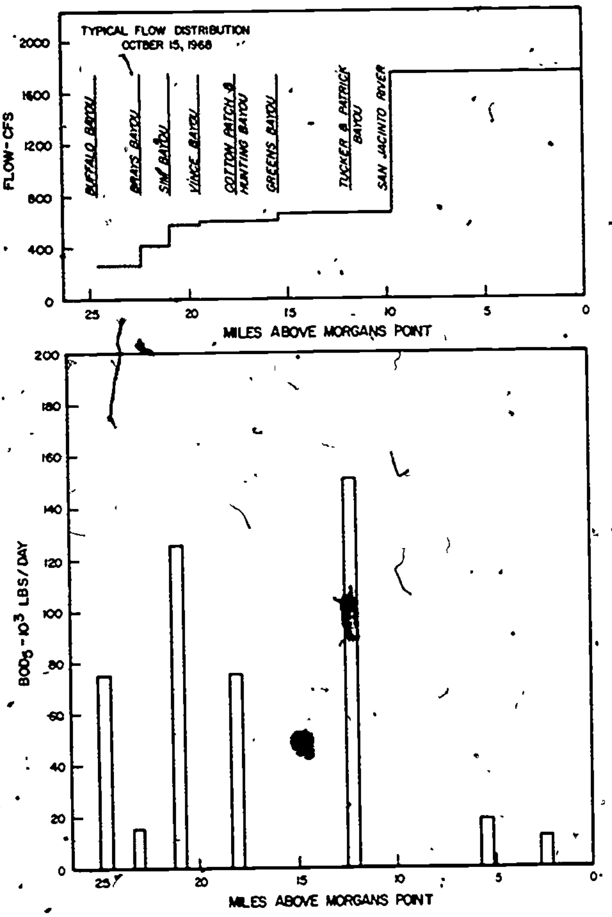


FIGURE 19.—Typical flow distribution and loading rate.

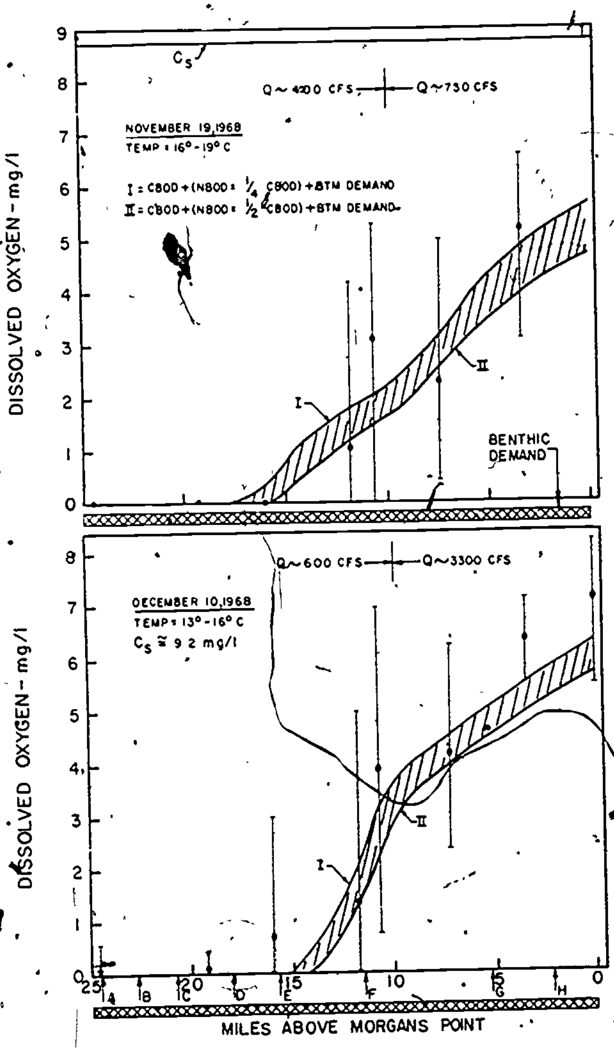


FIGURE 20.—Dissolved oxygen profiles, November and December 1968.

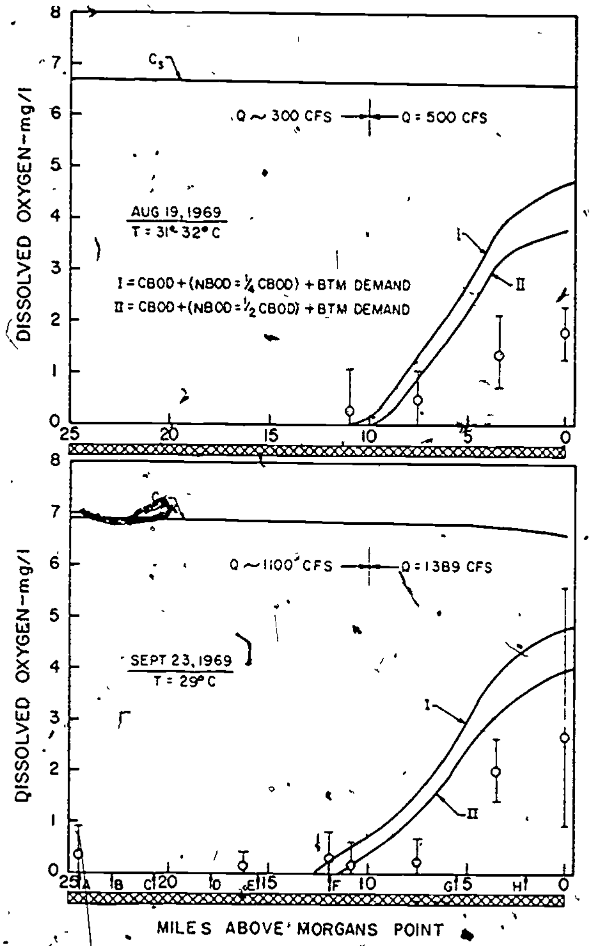


FIGURE 21.—Dissolved oxygen profiles, August and September 1969.

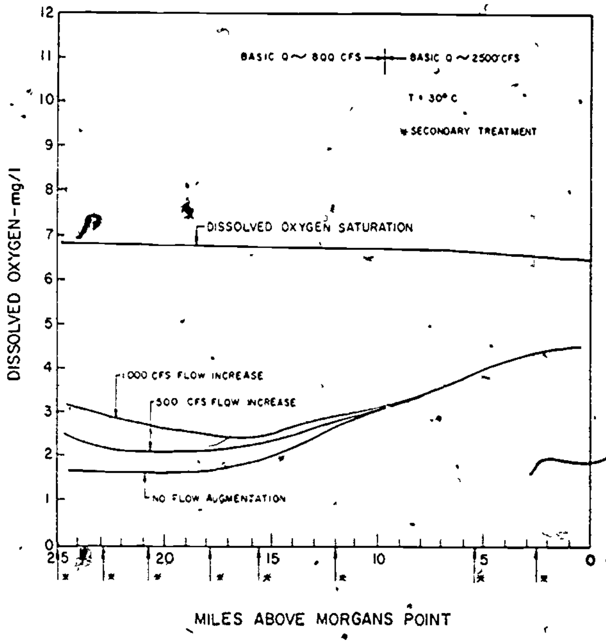


FIGURE 22.—Projected dissolved oxygen profiles flow augmentation.

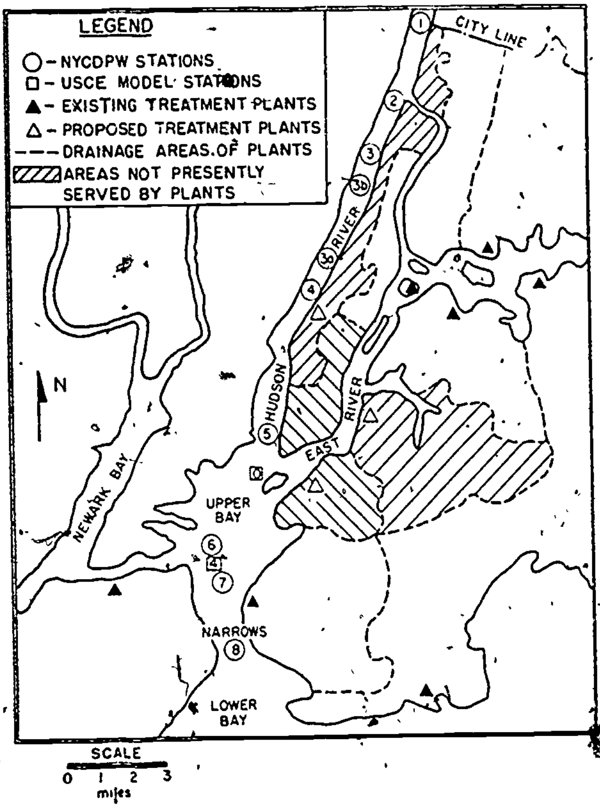


FIGURE 23.—Map of New York Harbor.

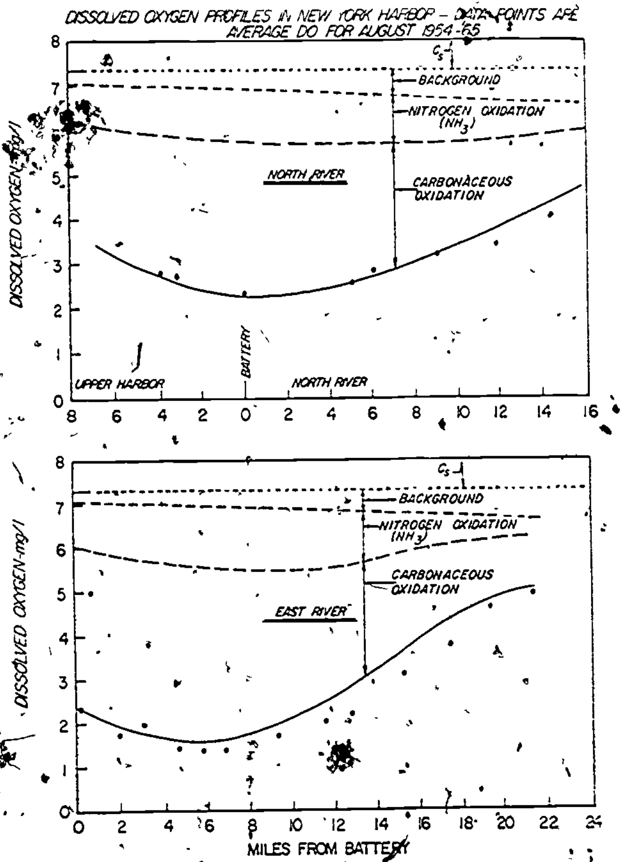

DISSOLVED OXYGEN PROFILES IN NEW YORK HARBOR - DATA POINTS ARE AVERAGE DO FOR AUGUST 1954-65

FIGURE 24.—DO profiles and components, average of August data 1954-1965.

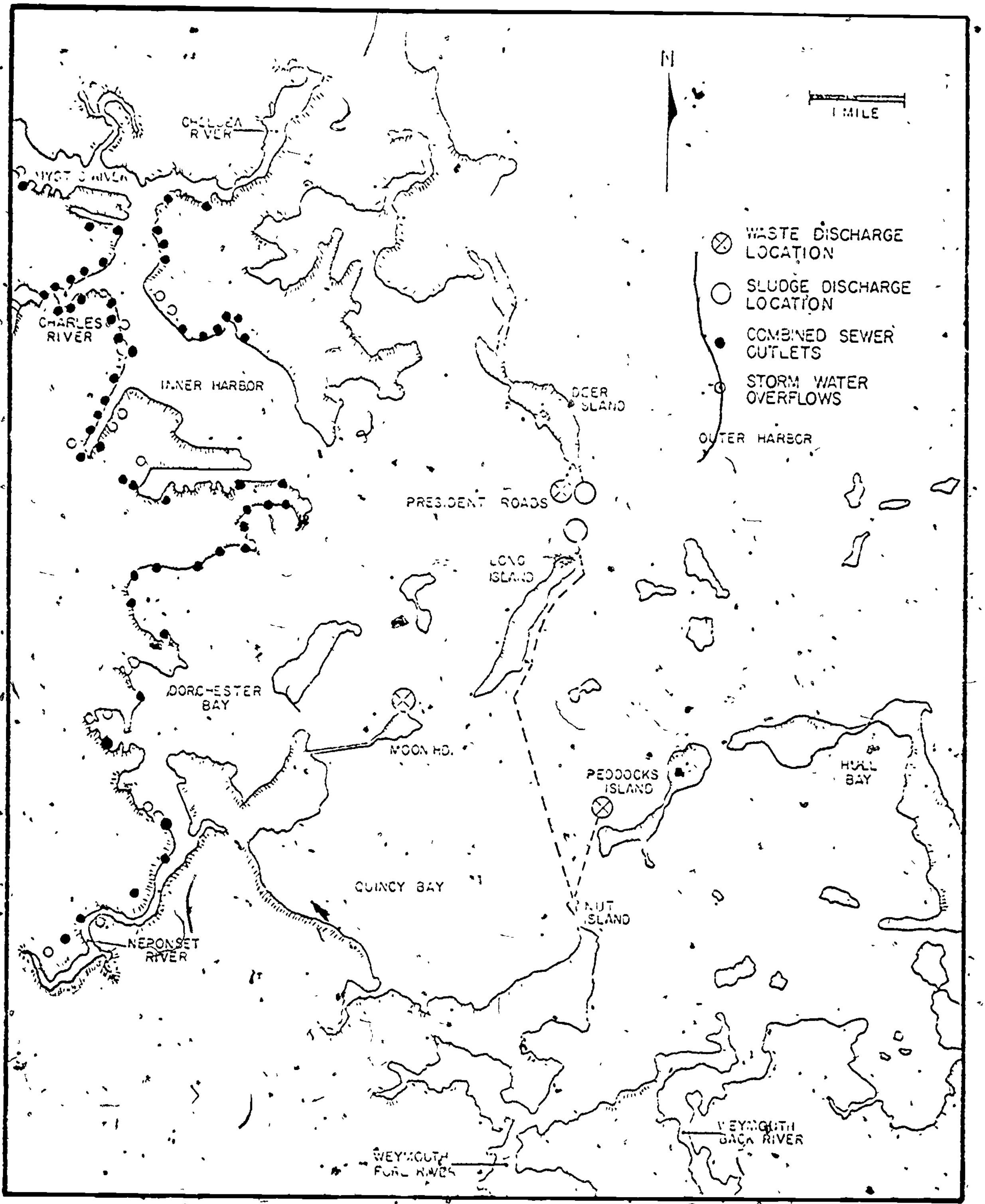


FIGURE 25.—Map of Boston Harbor.

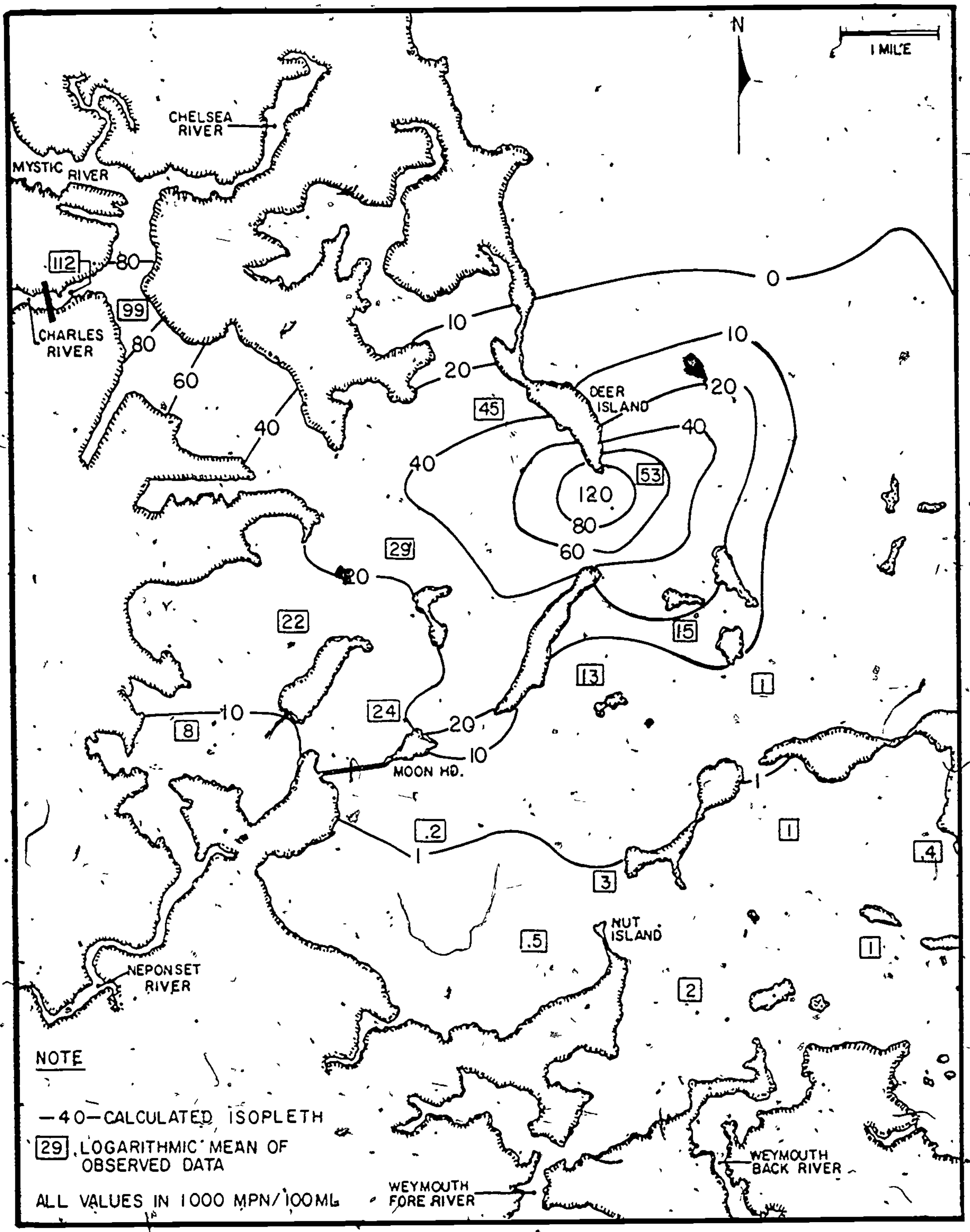


FIGURE 26.—Total coliform verification, Summer 1967.

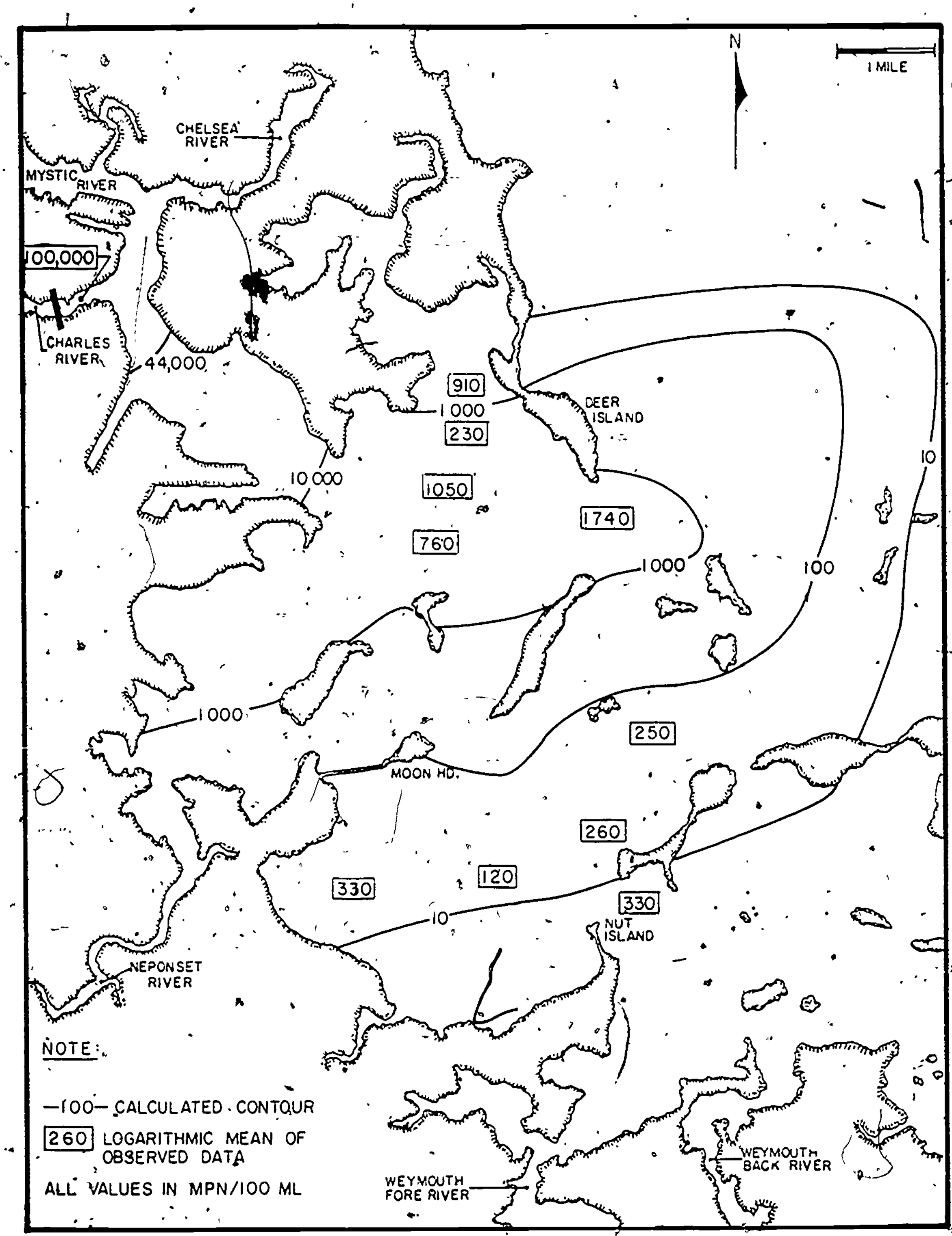


FIGURE 27.—Total coliform verification, Summer 1969.

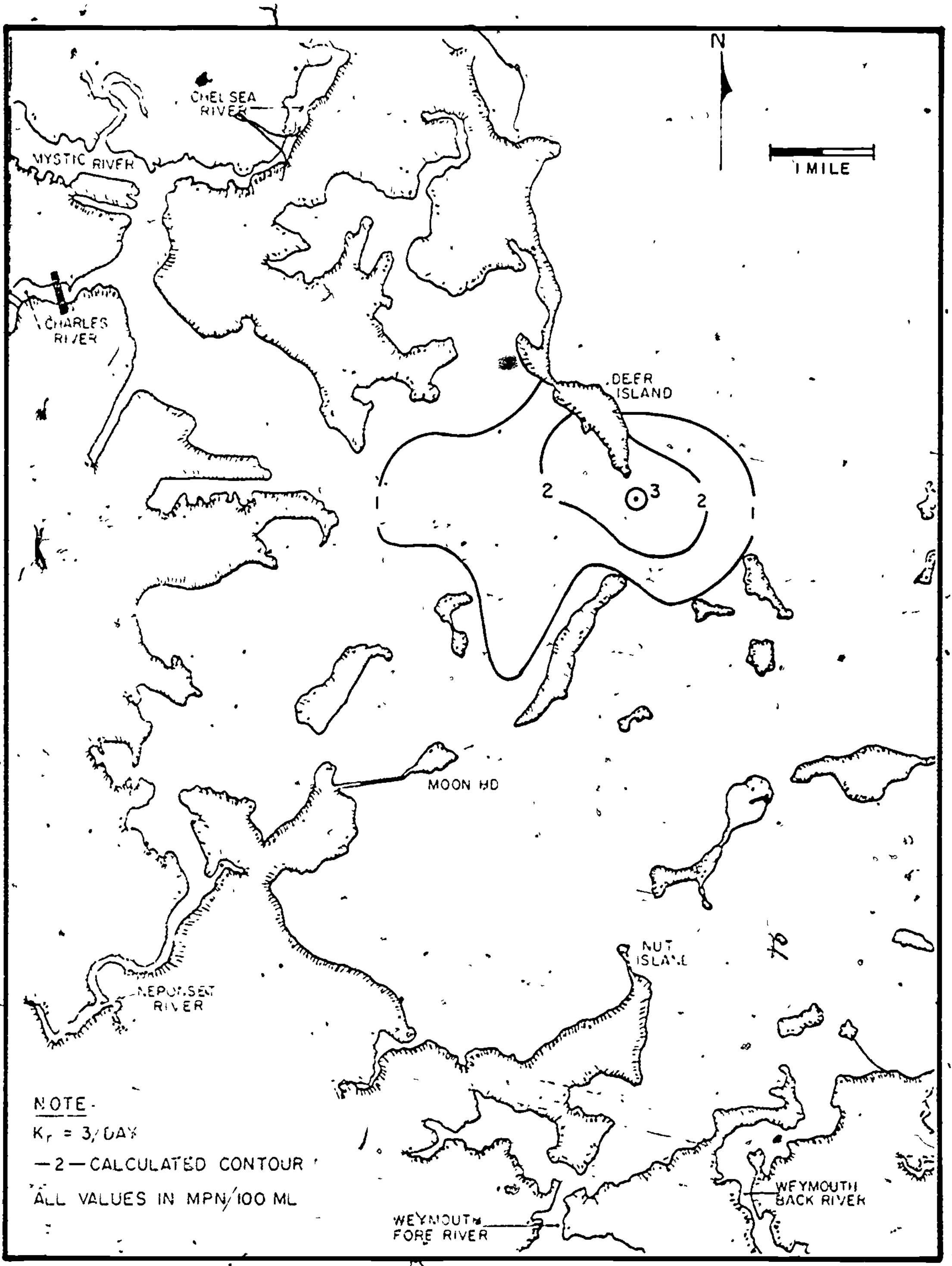


FIGURE 28.—Coliform distribution, effect of Deer ~~I and Nut I~~ effluents, Summer 1969.

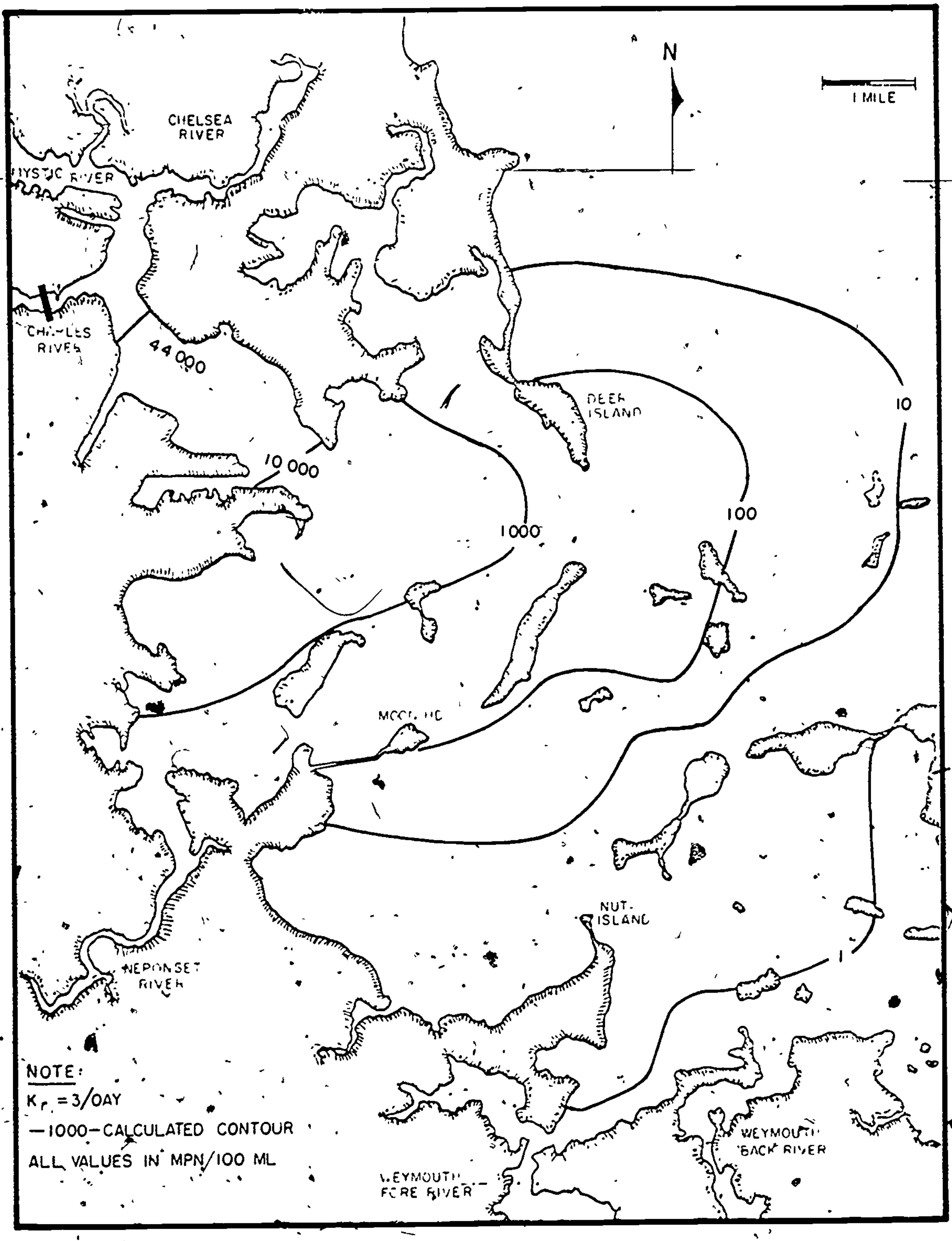


FIGURE 29.—Coliform distribution, effect of inner harbor loads, Summer 1969.

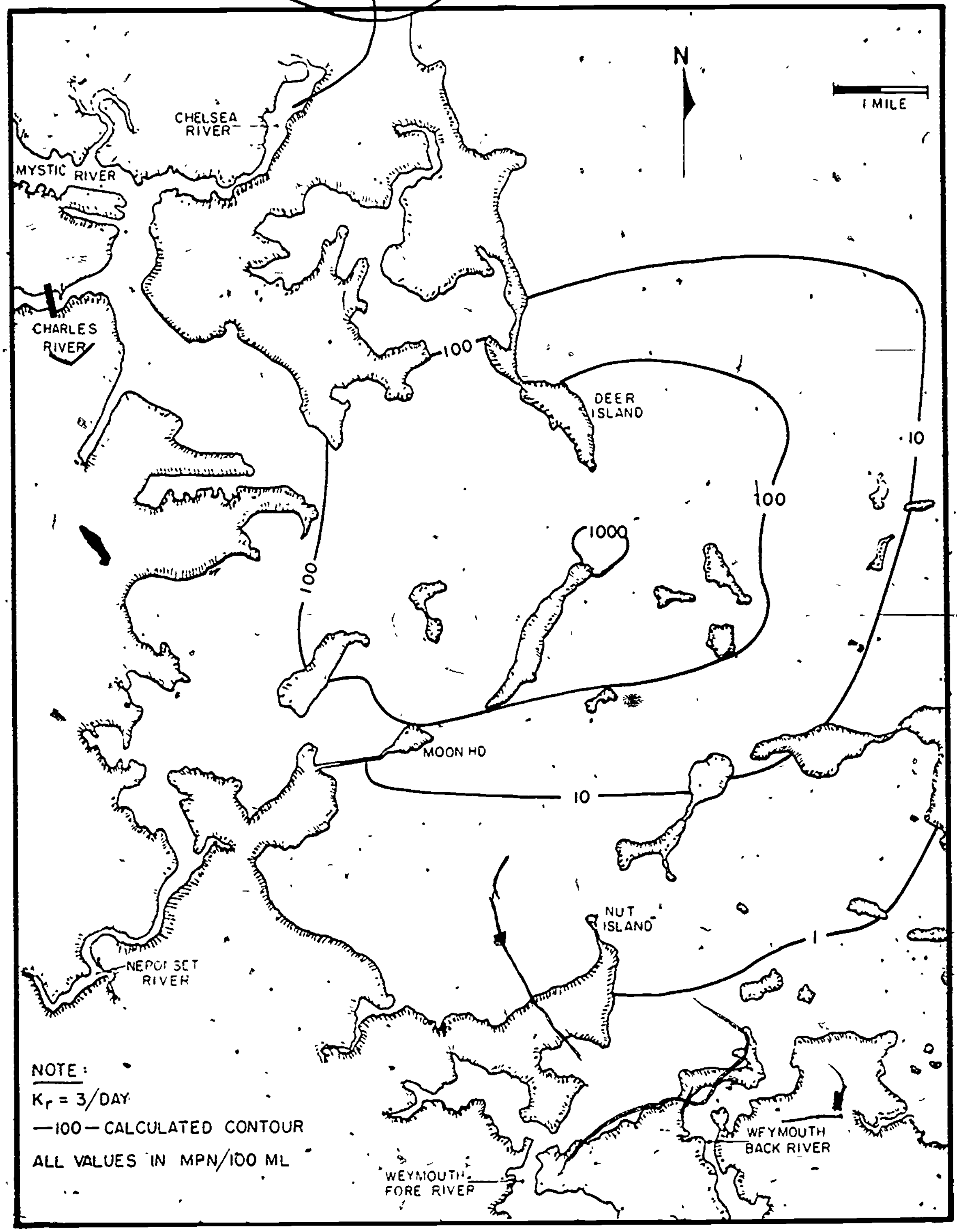


FIGURE 30.—Coliform distribution, effect of Deer I and Nut I sludges, Summer 1969.

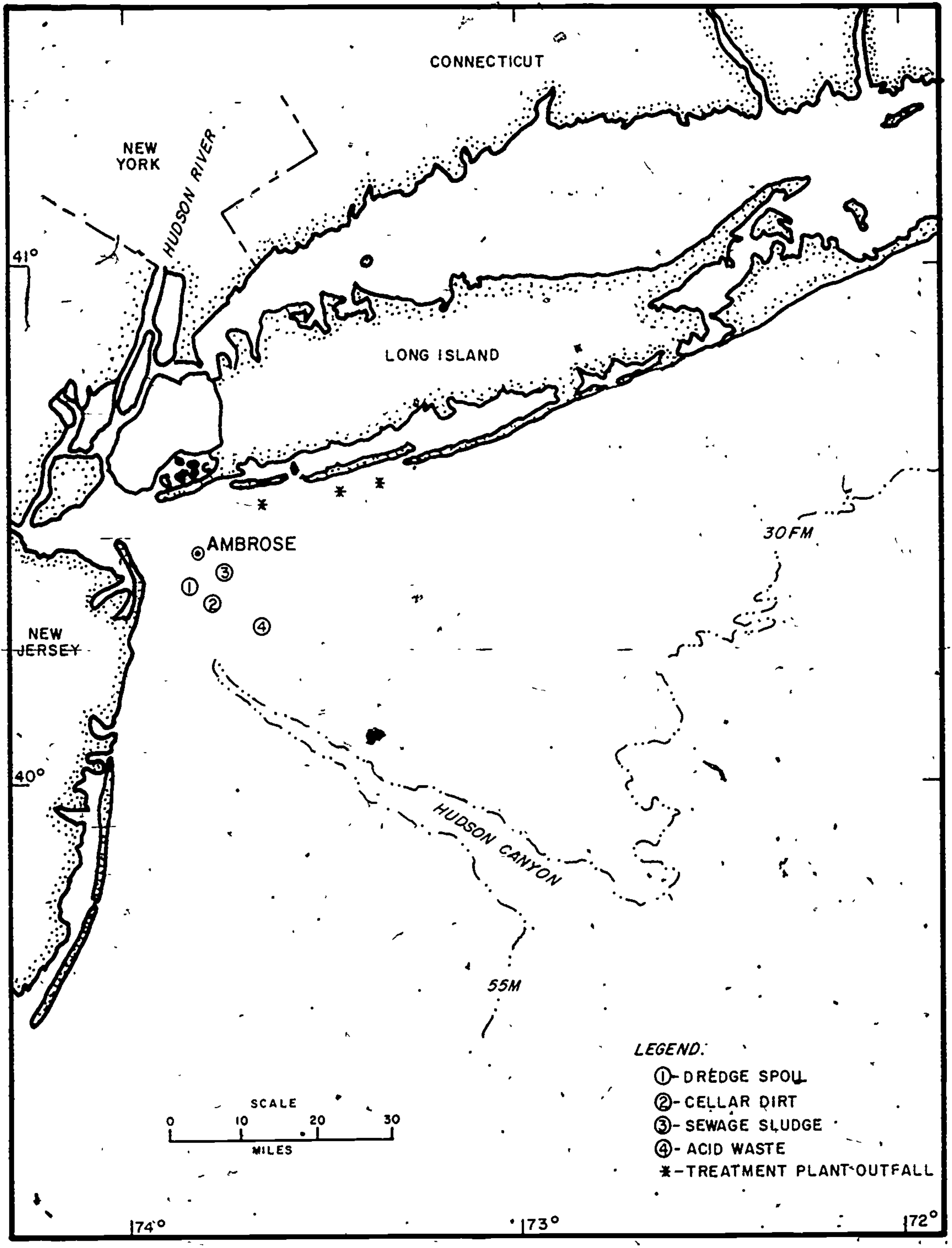


FIGURE 31.—Map of New York Bight.

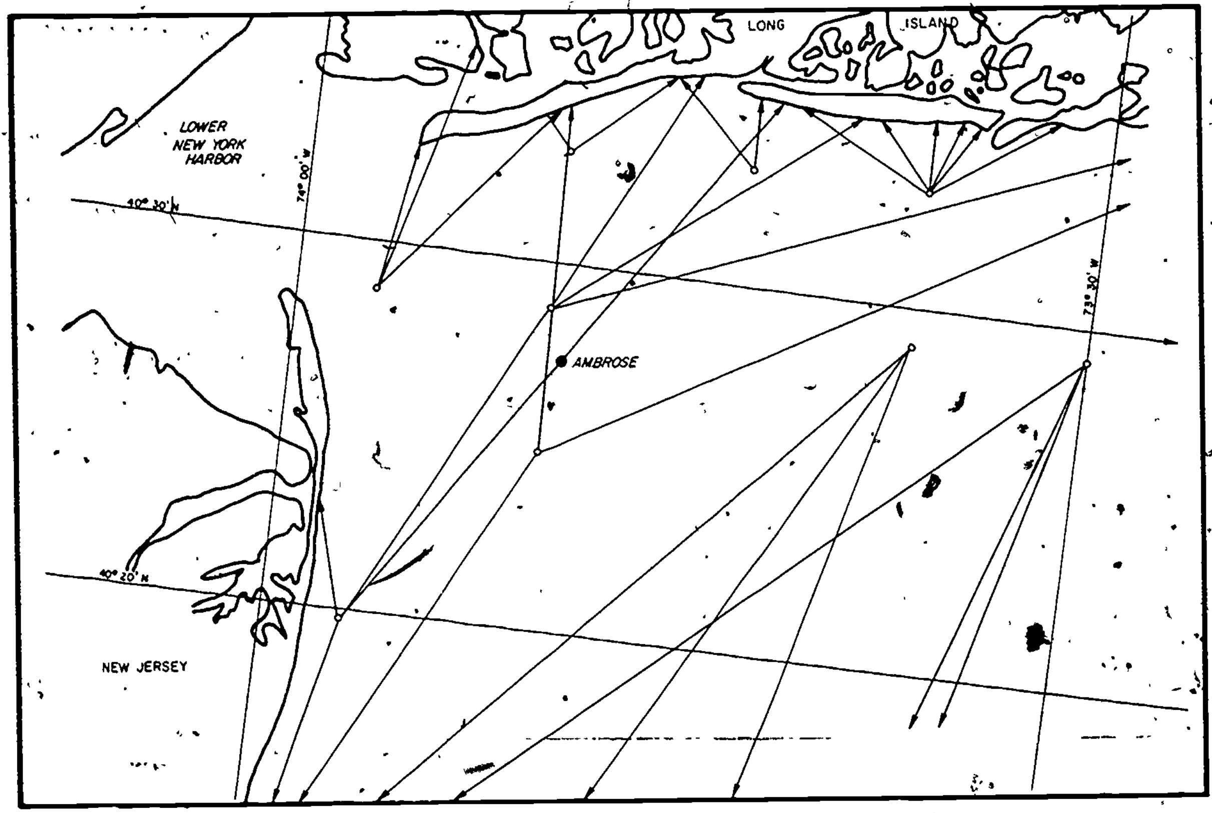


FIGURE 32.—New York Bight: June surface drifter vectors.

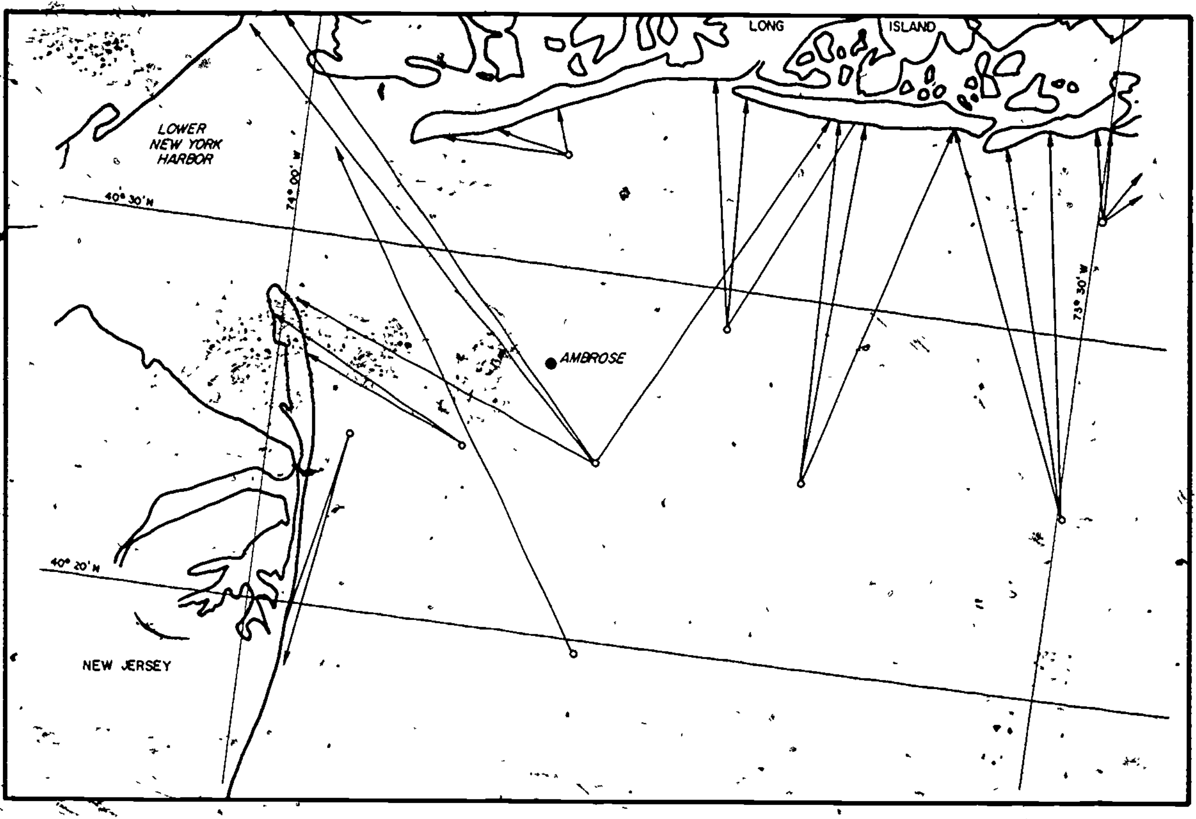


FIGURE 33.—New York Bight: June surface drifter vectors.

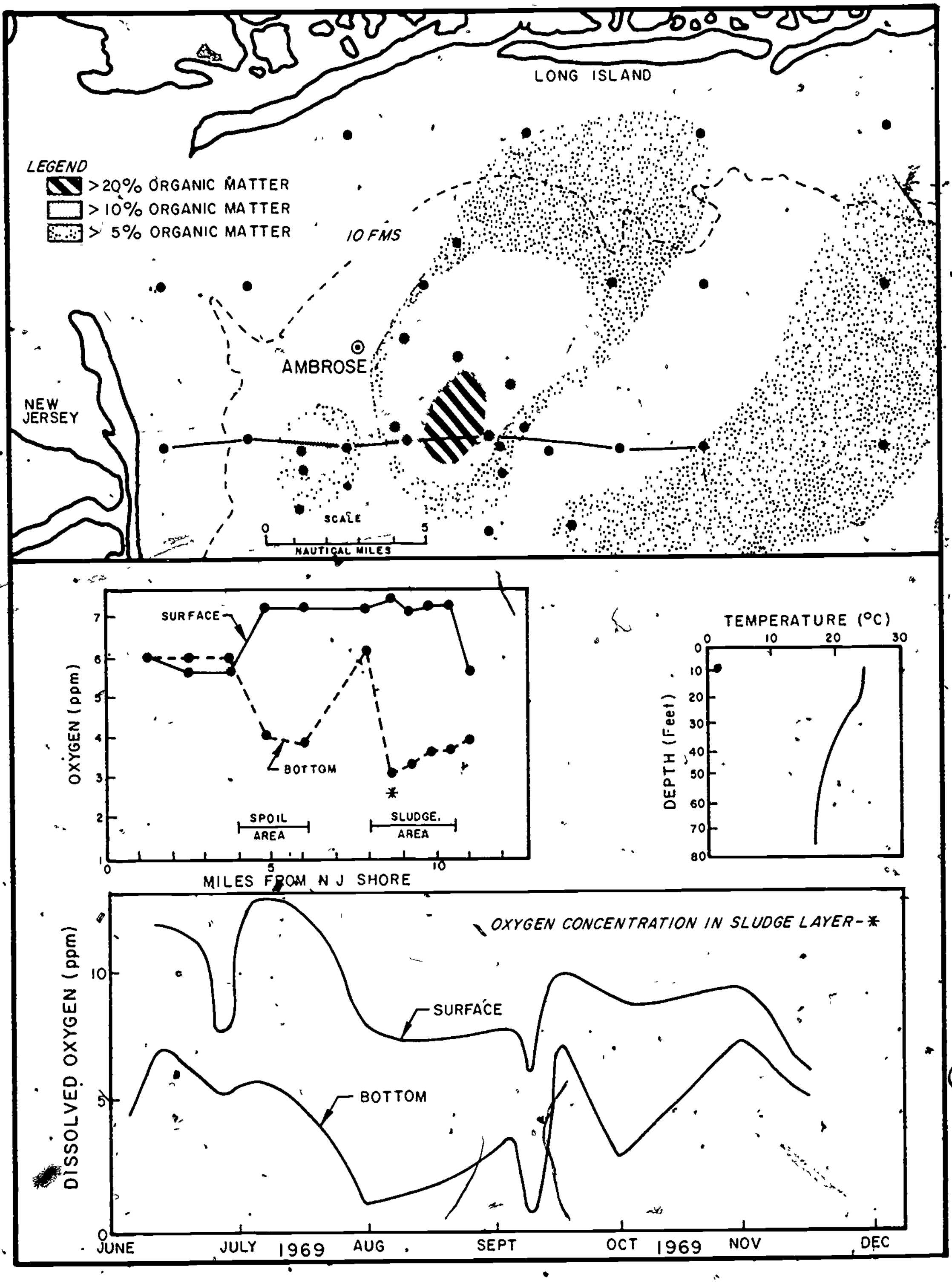


FIGURE 34.—Water quality conditions.

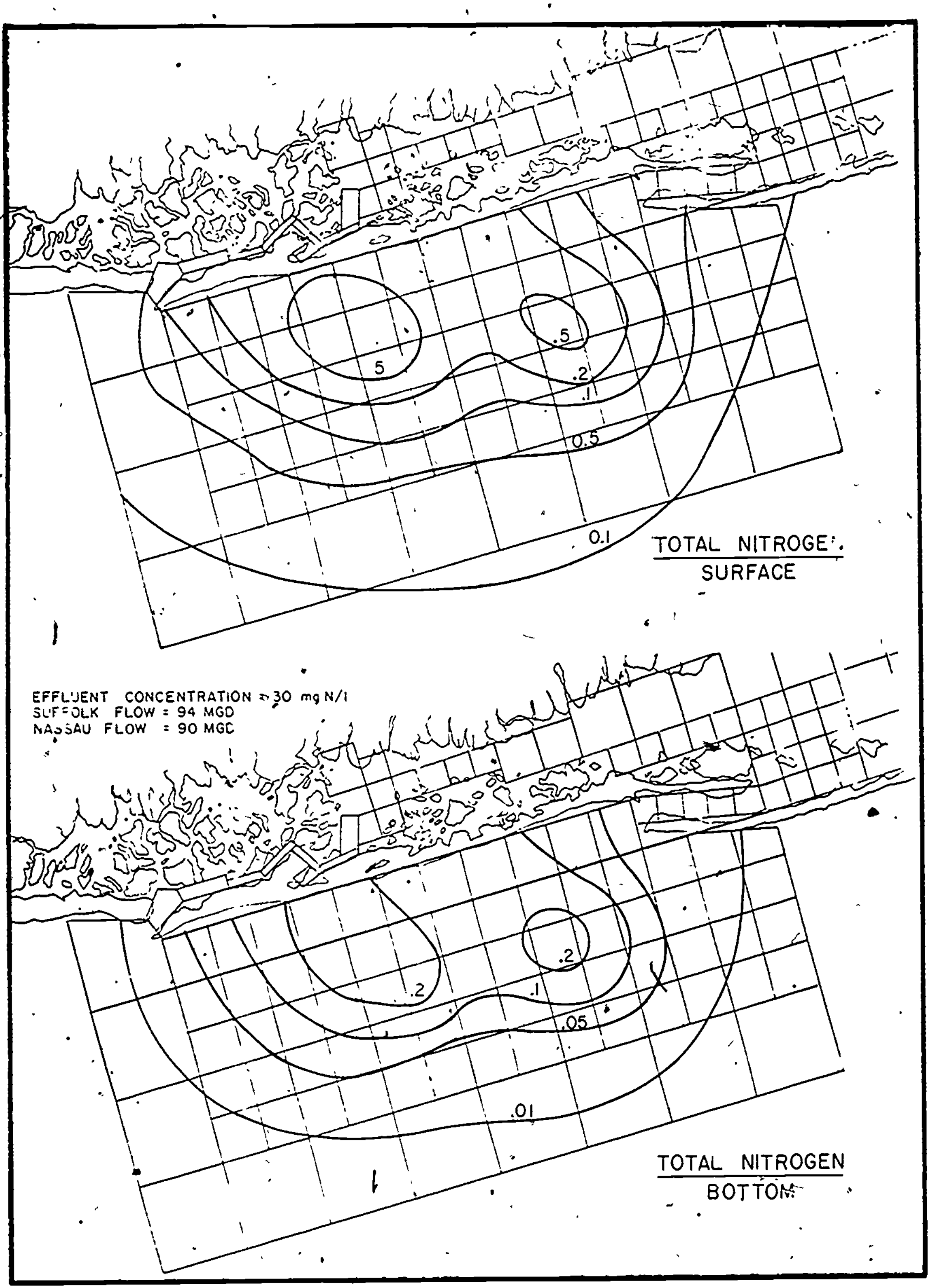


FIGURE 35.—Computed composite total nitrogen profiles.

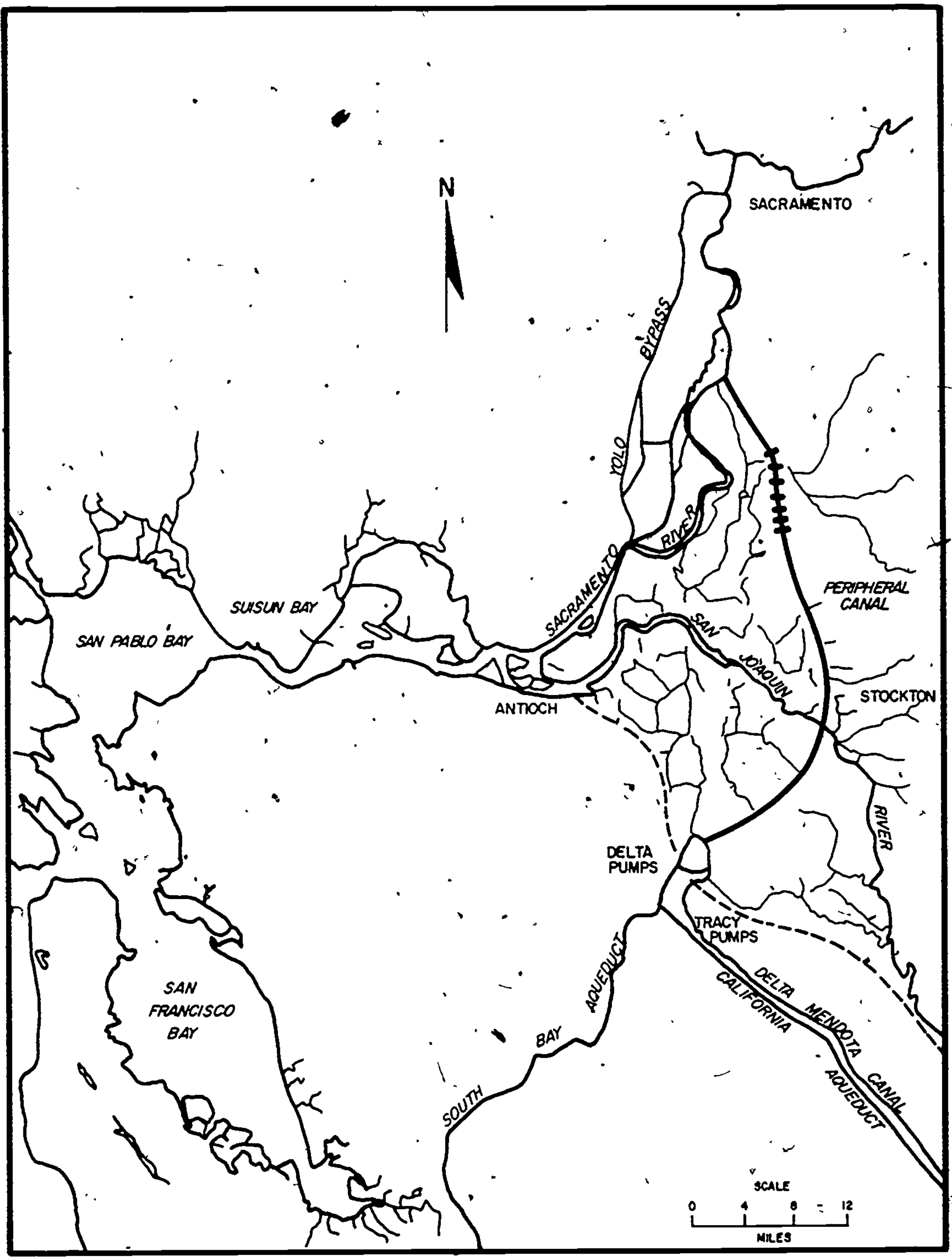


FIGURE 36.—Location map of proposed peripheral canal project.

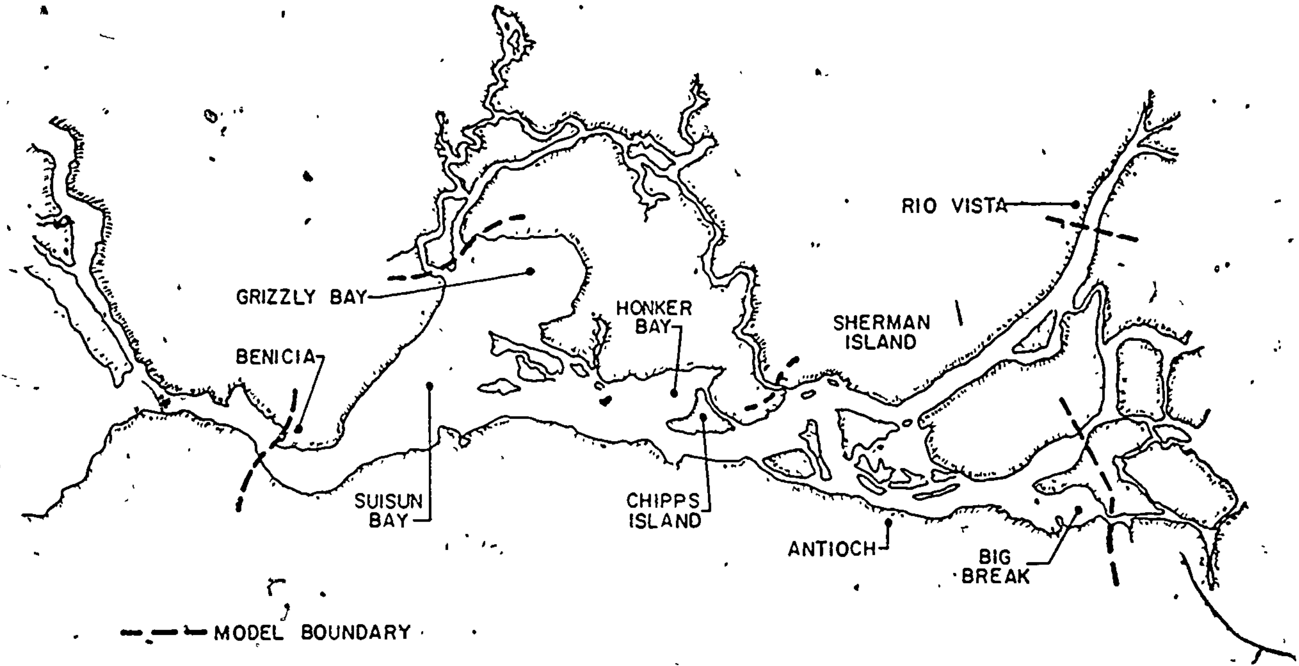


FIGURE 37.—Location map of study area.

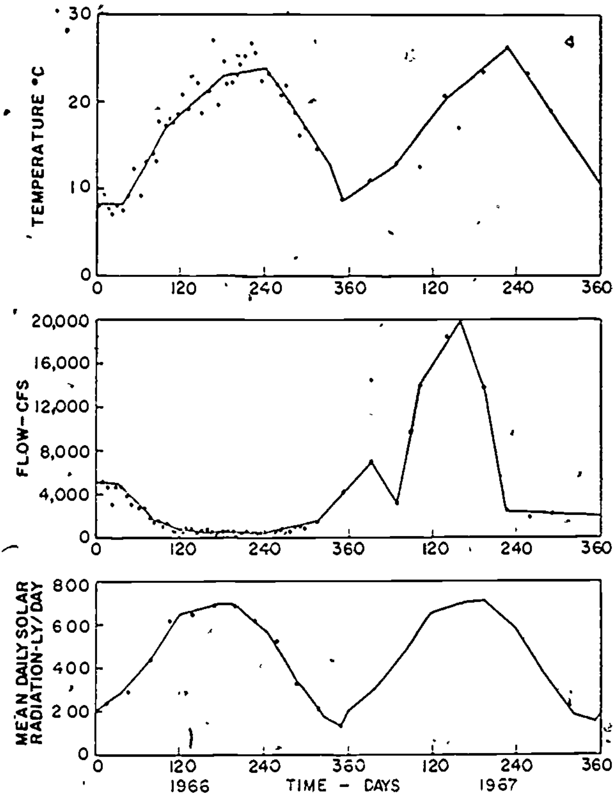


FIGURE 38.—San Joaquin River, Mossdale.

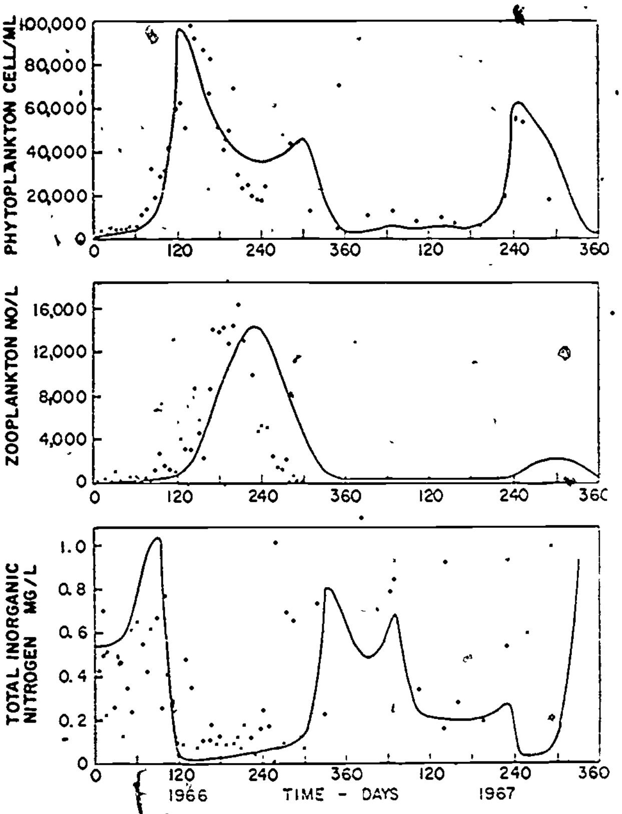


FIGURE 39.—Phytoplankton, zooplankton, and nitrogen: San Joaquin River, Mossdale.

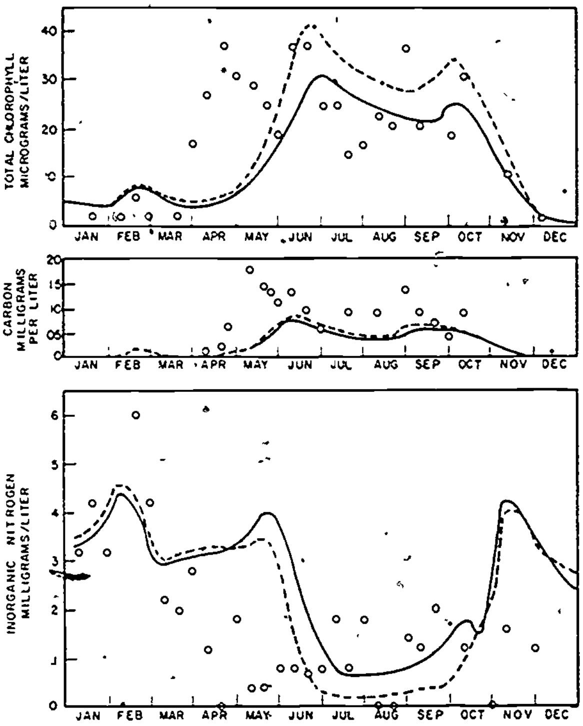


FIGURE 40.—Phytoplankton, zooplankton, and nitrogen: Antioch verification, 1966.

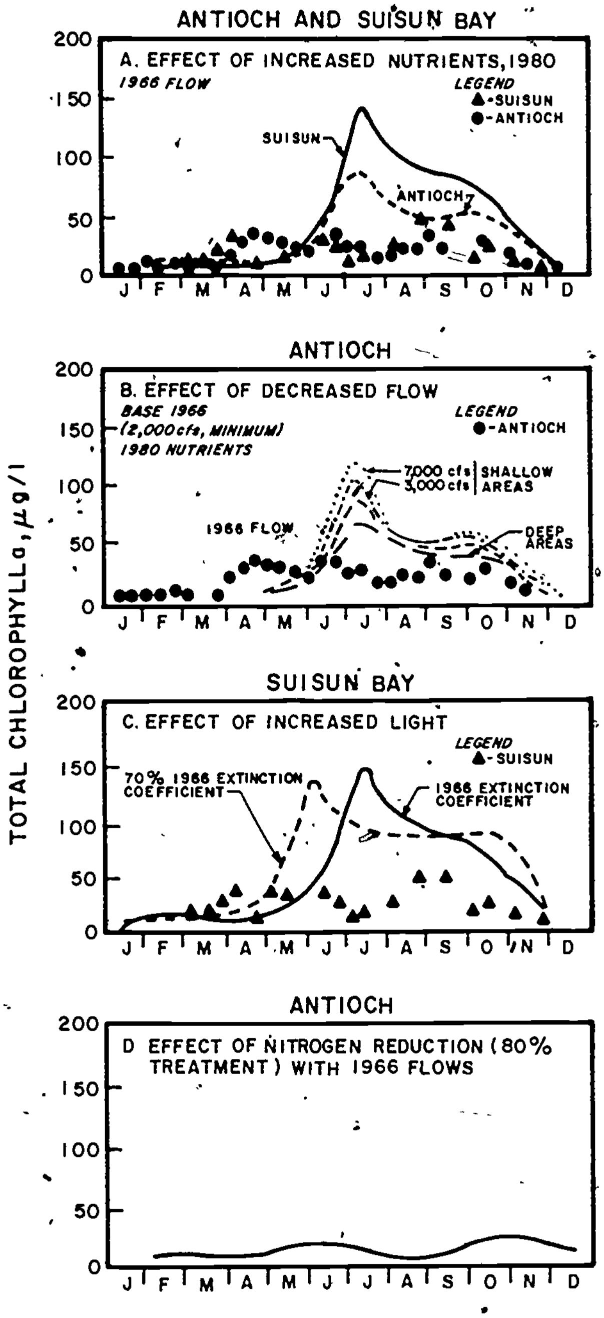


FIGURE 41.—Effect of increased nutrients, decreased flow, increased light, and nitrogen treatment.

DISCUSSION

Comment: On the last example you showed, would there be any payoff on the regulation of the use of fertilizer rather than treating afterwards?

Dr. O'Connor: I think so. I think it's an area to be looked at more. We didn't address that specifically, but I would certainly say that would be one that could be.

Comment: To what extent is it now becoming practical to introduce aquaculture factors into these types of equations, as in a case of physically extracting nutrients that are in excess?

Dr. O'Connor: I see that as something that's very much in the forefront. I don't see it as something that is practical immediately, but I support that development and I'm optimistic about it in the relatively near future.

I think we need a little more data on it, specific data, experiments, so we can see the data and then we can model better.

Comment: It seems to me that maybe there needs to be more support of this type of activity in the United States. The Japanese are way ahead of us. Considering the billions of dollars that are going to be spent on extraction of nutrients by sewage treatment, it seems relatively modest amounts of research might have a large payoff.

Dr. O'Connor: I subscribe to that 100 percent.

Comment: That was a tremendous presentation. A couple of things came out that the group is struggling with what about the integrity of water. I look at the integrity of my own body for instance, and it isn't a perfect thing. My body has integrity but it's not perfect. Do you have any thoughts about water and its perfection or its integrity? I'm finding it difficult to describe the problem, but we can't have complete zero of anything and we can't have complete perfection. What we have is something in between. I wonder if you could speak for a minute to that kind of proposition.

Dr. O'Connor: I'd like to speak about an hour on that kind of proposition. I don't know really how much more I can say. I do respond to the spirit of your question.

I think all of us, when we read the law, and even specifically our requests to appear here, we all asked ourselves more deeply, what we mean by the integrity. And I submit, it's basically a philosophical question, and maybe even a moral one.

I haven't got an answer, I keep looking for it. I think in some of the things I said I tried to address what nature is; it has bad parts and good parts. We look at it through jaundiced eyes; we assume we have the perfect vision.

It's good that optimism has pervaded our western culture for a good number of years. The easterners are much more realistic about it. I don't know what we can learn from them.

I am trying to say that given that, you always strive for these ideals. Maybe sometimes we strive too hard, or too high. Maybe they're good to have, but maybe we can regard them as ideals.

The final point, which I think follows, is that we interpret this in a pragmatic or enforcing way as zero discharge.

There's a certain point that we talk about in agriculture, a natural cycling of materials. There's some point where we can leave in some nitrogen and phosphorus. Do we really want to discharge sterile waters to our natural system?

I don't think that is in accord with what I observe as a natural law. So things like nutrients, and to a certain degree TDS, should be naturally recycled. That is part of zero discharge of pollutants but that doesn't mean distilled water.

On the other side are the synthetic compounds that industry is continuously manufacturing. They have to be reevaluated much more significantly, as I know some are, so they can break down to provide some of the basic nutrients.

That addresses the issue. I know it doesn't answer the question.

Comment: I think it opens up what is a pollutant? And we just go from one problem to another.

Dr. O'Connor: Exactly. When we think in terms of recycling, it's apparent that zero discharge is not part of it. The law is a little ambiguous that way, it was written from that point of view, the idea of a natural cycling of materials, to which I think, by and large, everyone subscribes.

It automatically follows therefore, that there's no zero discharge that will be going through recycling. If we don't recycle onto the water then we're going to recycle onto the land. Maybe that was what we presupposed.

I think the water has to be nourished just as the land has to be nourished. It's balanced. We're not at the stage of saying what the balance is, but I do agree with you.

Comment: In Texas you showed a significant amount of pollution appeared, and you ordered the oxygen profile for the channels in question. I was curious to know if we can infer from that that lowering of the amount of deoxygenating waste in the stream can occur without the stream flow showing similar effects?

What I am trying to get at is: are there some kinds of stream channels, particularly in canal systems, which are so limited in their reaerating capacity that we have a limited return on our [waste treatment] investment?

Dr. O'Connor: Yes. I respond to your question positively. That's about it. The significant input of the San Jacinto, is that what you're thinking of? Where that comes in, you would have expected a more pronounced influence in dissolved oxygen.

That is due to two reasons. One you alluded to, the artificial deep channel there, 30 or 40 feet. When you start to do things like that, there's a point of no return.

I think they would be better off in many ways if, in the future, we can think more in terms of 20-foot channels. There are limits on exact relationships, and they may, economically and ecologically, be best.

The second factor is that the tidal influence is a balance between the tidal effects and the freshwater effects. Perhaps it's not too specific, but, yes, your first point is properly taken.

Comment: You made the statement that a model is just a planning tool. We're now using a model as a regulatory tool in many areas. What kind of success do you expect we'll have if challenged in the courts? Will the court understand what we've done, what kind of success we expect in this area?

Dr. O'Connor: That's a good question. We talk about all the disadvantaged people in our society, I think some of the most disadvantaged are the judges. Can you imagine what they're faced with, with these court actions? You're going to line up all the experts in the world, regardless of what side they're on, and how does the poor judge get this unraveled?

I think what we have to do, and I hope I'm answering your question, but I think what we have to do with groups like ourselves, regardless of whom we represent, is to offer our services to the judge. There should be a third facet to evaluate these two things.

Our system was structured on the government balancing industry. Say they are unbalanced, how do you side between these two? I think we have to structure another facet that gives advice to the judge.

That advice would take on the evaluation as to what degree, first, how representative are those, whatever the issue might be. That is, has the man extracted "the relevant features."

Second question: what degree has been calibrated and validated. And then how far are we carrying that extrapolation? Are we really taking it, are we close to it?

These would be the criteria by which, and I believe having had the experience, that California work was a public hearing, and in essence it was a court case, the local people took the Department of Water Resources to court, and we represented the Department in that case. Five men heard the case, and there was only one with technical training.

It took a long time to describe this, but it did work, and I think it can work, if judges are that type. But, having had that experience, I do support, strongly, that the judge should have a much greater budget available for his own evaluation, instead of getting this contradictory evidence from two experts. That's the difficult part, but I think it can work.

Comment: Do you have any doubts on lowering the phosphorus level and the validation of that?

Dr. O'Connor: I indicated in this last project that I was only looking at nitrogen. The reason being that phosphorus was plentifully available from the natural input. There's phosphorus mining and it's in the ground water. And the phosphorus levels were far in excess of the saturation contents. In a number of other systems, however, the phosphorus level can be the limiting factor, as it appears to be, to some degree, in the Great Lakes system.

What's simplistic about what you just suggested, and I think maybe you realize it, is that really it's a product of those two nutrients and maybe every other. Whatever form that particular equation takes, the growth coefficient in these equations has to reflect, in a product fashion, a nonlinear fashion, the concentration of all the relevant nutrients.

Consequently, and you know the type of curve that is usually used, so we can fall up and down that thing, to call something limiting is very deceiving. Any place along that curve there are combinations. In our recent work in Lake Ontario, at one time of the year phosphorus was limiting, in the sense that it was below the curve, and in the fall, the latter part of the summer, it was nitrogen.

I'm very wary of the "let's remove all the phosphorus" because of good qualitative reasons. But we're dealing with nonlinear systems, and that's why, in general, I'd be very leary of any such statement that this or that is limiting. Did I address the question?

Comment: In relation to that, we have algae in the stream, and we're attributing that to phosphorus.

Dr. O'Connor: Does the field data bear that out too? I would still try to validate a model for that system, before I moved in that direction.

Comment: Talk about your efforts in the so-called eutrophication models and studying them to such an extent that you really understand the system. There are a couple of empirically-based models, if you want to call them that, that are sort of black box approaches, empirically-derived relationships on observed data. Is that the kind of thing you see coming forth?

Dr. O'Connor: I would hope so, but from my understanding of the phenomenon involved now, I think perhaps they are too simplistic. They were excellent first steps in giving some understanding, but, in that case, I think the direction has been oversimplification.

It is a limiting situation, and we'll be reporting on this in the near future, my colleagues and myself, to show that this approach fits into what we are doing, and to indicate that it is a limiting situation.

That's why, when you try to correlate data to this approach, you see the usual scatter problem. It's the right idea, but too simple, as I see it. That's a rather qualitative opinion.

Comment: There is a mass of data, based on studies designed to apply that. The working papers are coming out, and a lot of them fall pretty much into the model, as proposed.

Dr. O'Connor: It's like using any good piece of information. Use it within the limits for which it was constructed. These are reasonable guides, but, maybe because I've gone the other route, I'm wary of them. Maybe I haven't got the totally unprejudiced eye.

Comment: One thing, I'm not too sure of the limits of the approach, and if they have been well defined. The original work is rather large.

EFFECT OF PHYSICAL FACTORS ON WATER QUALITY

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INTRODUCTION

The most important physical factor affecting the water quality of a natural water body into which wastes are discharged is the state of motion of the receiving water. Waterways, whether they be lakes, reservoirs, rivers, estuaries, or the oceans are seldom stationary except for relatively short periods of time. Furthermore, the act of discharging a waste will in itself produce motion by jet diffusion. Motion of the receiving water may also be generated by gravitational forces, wind stress at the water surface, astronomical tidal forces, or atmospheric pressure variations. The resulting flow is affected by frictional forces producing turbulence and dispersive mixing processes. Density variations caused by gradients of water temperature, suspended sediments, or dissolved salts may augment or hinder the shear-induced mixing processes. Thus, distributions of temperature, salinity, and solids are important physical factors affecting water quality both through their influence on the transport processes and by their effect on biochemical transformation rates.

The improvement and control of water quality in a natural water body such as a river or estuary can be achieved by intelligent regulation of municipal and industrial waste discharges. Waste treatment techniques by chemical and biological processes are highly developed, and while it is technically possible to approach "zero discharge" of wastes, in most cases it is neither necessary nor economically feasible to do so. The important engineering decisions in water quality control relate to the determination of the level of waste treatment that is consistent with the multiple uses of natural water bodies. This implies the ability to forecast or predict the response of the river or estuary to future increases in investment in waste treatment facilities.

The prediction by mathematical or physical models of effects and benefits in advance of the construction of a facility, is the essence of engineering. Physical models are of limited use in water quality studies because of the difficulty of simulating biochemical reaction processes at reduced temporal and spatial scales. Within the last decade engineers and planners have made increasing use of mathematical models for planning purposes. The objective of this paper is to present some recent developments and future research directions for mathematical models for water quality control and to illustrate the important coupling between physical factors, represented by hydrodynamic transport processes, and biochemical water quality parameters.

The models used for illustration were developed at MIT over the past 5 years. Since this paper is not intended to be a state-of-the-art review or a critique of various modeling approaches and solution techniques, the lack of reference to comparable models developed by other investigators is justified only in the interest of brevity.

STRUCTURE OF WATER QUALITY MODELS

All mathematical models are approximations, in varying degrees, of the natural processes which they attempt to represent in a deterministic manner. In an ecosystem as complex as a river or an estuary there are a large number of possible approximations within the conceptual framework of simulation models. Any water quality model containing a number of "rate constants" can be made to agree with field data by the familiar process of curve-fitting. However, there is no guarantee that a particular model will give valid results when used in a predictive role. It is important that the user or developer of a water quality model have the ability to analyze the structure of the model and to judge the validity of basic assumptions.

Various strategies can be identified for structuring mathematical models of aquatic ecosystems. Table 1 identifies three basic types of models:

Table 1.

Type of model	Organizing principle	Causal pattern	Measure
Biodemographic models	Conservation of species or of genetic information	Life cycles	Numbers of individuals or of species
Bioenergetic models	Conservation of energy	Energy flow circuits	Energy power
Biogeochemical models	Conservation of mass	Element cycles	Mass of elemental matter

Fisheries management models usually belong to the class of biodemographic models, as they are concerned with particular species and the processes that affect their numbers, such as birth, death, harvesting, and competition. Bioenergetic models are concerned with energy-flow, energy-storage, and energy-dissipation processes simultaneously coupling ecological and environmental components.

Most water quality engineering models fall into the category of biogeochemical models. They employ the principle of conservation of mass to determine the distributions of dissolved oxygen, nutrients, and biomass by the coupling of hydrodynamic transport and biochemical transformation processes. The remainder of the discussion will be concerned with biogeochemical models as applied to water quality control in estuaries.

BIOGEOCHEMICAL WATER QUALITY MODELS

The hydrodynamic aspects of an estuary are the transport processes which include the advection, mixing, and dispersion of specific constituents in waste effluents. In addition, these constituents are subjected to various transformation or reaction processes leading to their production and/or decay. Transport processes are relatively independent, or at least insensitive, to the characteristics of the wastes introduced into a waterway. The transformation processes, on the other hand, depend on both the transport processes and on the interaction or coupling of constituents of the total waste load.

The essential features of biogeochemical models may be illustrated by considering the one-dimensional formulation in which cross-sectional areas, velocities, and concentrations are functions of longitudinal distance, x, and time, t.

ADVECTIVE TRANSPORT PROCESSES

In general, the transport processes are unsteady, therefore the advective terms which describe the flow field must be determined by simultaneous solution of the continuity and momentum equations. The governing equations for one-dimensional flow in a variable area channel are:

the continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad (1)$$

and

the longitudinal momentum equation

$$\frac{\partial}{\partial t}(AU) + \frac{\partial}{\partial x}(QU) = -gA\frac{\partial h}{\partial x} - g\frac{Q|Q|}{AC^2R_h} - \frac{gAd_c}{\rho}\frac{\partial \rho}{\partial x} \qquad (2)$$

where

x = distance along longitudinal axis

t = time

h = elevation of water surface with respect to a horizontal datum

Q = cross-sectional discharge

q = lateral inflow per unit length of channel

U = average cross-sectional velocity in the channel, = Q/A

g = acceleration of gravity

A = cross-sectional area of channel

C = Chezy roughness coefficient

R_h = hydraulic radius of channel

ρ = density of water

d_c = distance from surface to centroid of the cross section

The last term in equation (2) represents the effect of a longitudinal density gradient. This term is significant only within the salinity intrusion region of estuaries. Boundary conditions must be specified (either water surface elevation, h, or discharge, Q) at the upstream and downstream sections of the river or estuary being modeled. The solution of equations (1) and (2) can be obtained numerically by means of finite-difference schemes as described by Harleman and Lee.[1] The solution requires the specification of initial conditions for h and Q and advances in time in accordance with the values of the time varying boundary conditions.

CONSERVATION OF MASS

The basic components of biogeochemical water quality models are statements of conservation of mass. Essentially the model consists of a sequence of conservation of mass equations, one for each water quality constituent.

The one-dimensional, conservation of mass equation may be written in the following form:

$$\frac{\partial}{\partial t}(AC) + \frac{\partial}{\partial x}(QC) = \frac{\partial}{\partial x}\left(AE_L \frac{\partial C}{\partial x}\right) + A\left(\frac{r_i}{\rho} + \frac{r_e}{\rho}\right) \qquad (3)$$

where

C = concentration of a water quality constituent (averaged over the cross section)
E_L = longitudinal dispersion coefficient
r_i = time rate of internal addition of mass of substance C per unit volume by transformation or reaction processes
r_e = time rate of external addition of mass of substance C per unit volume by addition of substance across the lateral, free surface and bottom boundaries of the system.

The hydrodynamic variables Q or U, and h or A, obtained by solution of equations (1) and (2) are basic inputs to the transport terms on the left-hand side of equation (3). The longitudinal mixing process is represented by the first term on the right-hand side and the internal and external "sources" or "sinks" of the particular water quality constituent, represented by C, are contained in the last term.

Many transformation processes are dependent on the local temperature (T) and/or salinity (S) of the water and it is convenient to determine T = f(x,t), and S = f(x,t) as static variables defining the water environment. The quantity ecT represents the concentration of heat per unit volume of water. Therefore with C = ecT, equation (3) can be written as a conservation of heat equation:

$$\frac{\partial}{\partial t}(AT) + \frac{\partial}{\partial x}(QT) = \frac{\partial}{\partial x}\left[AE_L \frac{\partial T}{\partial x}\right] + \frac{\phi_n b}{\rho c} \qquad (4)$$

where

T = water temperature
ϕ_n = time rate of net heat input per unit area of water surface
b = water surface width
ρc = (density) (specific heat of water)

In equation (4), the last term represents a source of the external type, i.e., the net rate at which heat is transferred across the water surface by the combined processes of long-and short-wave radiation, evaporation, and convection.

Examples of the simultaneous solution of equations (1), (2), and (4) to find T = f(x,t) using numerical techniques are given by Harleman, Brocard and Najarian.[2] In rivers and in the uniform density portion of estuaries (not including the salinity intrusion region), the longitudinal dispersion term in equations (3) and (4) is of secondary importance. Values of the longitudinal dispersion coefficient in rivers and estuaries may be estimated on the basis of the work of Holley, Harleman, and Fischer.[3]

In estuaries where salinity intrusion occurs, longitudinal dispersion becomes an important factor in the overall mixing process. This is due to the gravitational circulation induced by the freshwater-seawater density difference. The conservation equation for salinity is given by:

$$\frac{\partial}{\partial t}(AS) + \frac{\partial}{\partial x}(QS) = \frac{\partial}{\partial x}\left[AE_{LS} \frac{\partial S}{\partial x}\right] \qquad (5)$$

where

S = salinity
E_{LS} = longitudinal dispersion coefficient in the salinity intrusion region

Equation (5) is an example of a "conservative" conservation of mass equation; in general, there are no internal or external sources of salinity except at the ocean boundary. Thatcher and Harleman[4,5] use numerical techniques to solve equations (1), (2), and (5) to find S = f(x,t). They use a dispersion relationship in which E_{LS} is a function of the local longitudinal salinity gradient and the degree of vertical mixing in the estuary. Applications to unsteady salinity distributions in the Hudson, Delaware, and Potomac estuaries under time-varying freshwater inflows are given.

TRANSFORMATION PROCESSES

CBOD-DO MODELS

Historically, water quality models have emphasized the importance of dissolved oxygen (DO) as the primary indicator of water quality. The earliest and most elementary example of a transformation process, within the framework of biogeochemical models, is the concept of carbonaceous biochemical oxygen-demand (CBOD). This class of models has its origin in the water quality studies of Streeter and Phelps beginning about 1925. The coupling between the set of conservation of mass equations for CBOD and DO is illustrated by the following forms of equation (3):

Conservation of CBOD:

where

$$\frac{\partial}{\partial t}(AL) + \frac{\partial}{\partial x}(QL) = \frac{\partial}{\partial x}\left(AE_L \frac{\partial L}{\partial x}\right) - K_1 AL \qquad (6)$$

where

L = ultimate carbonaceous biochemical oxygen demand (CBOD)
K_1 = CBOD decay coefficient

Conservation of DO:

$$\frac{\partial}{\partial t}[A(DO)] + \frac{\partial}{\partial x}[Q(DO)] = \frac{\partial}{\partial x}\left[AE_L \frac{\partial (DO)}{\partial x}\right] - K_1 AL + K_2 A[DO_s - DO] \qquad (7)$$

where

DO = concentration of dissolved oxygen
DO_s = saturation concentration of dissolved oxygen
K_2 = surface reaeration coefficient

The elementary coupling arises from the fact that the solution of equation (6), $L = f(x,t)$, appears in equation (7) as the internal decay term for dissolved oxygen. Dailey and Harleman[6] have developed numerical methods for simultaneous solution of equations (1), (2), (4), (5), (6), and (7) in estuarine networks of one-dimensional channels.

The fundamental limitations of the CBOD - DO class of models are well known and will not be discussed in detail. It is sufficient to say that it is essentially impossible to aggregate biogeochemical transformation processes within the concept of CBOD as a primary water quality constituent. In addition, dissolved oxygen is not a sufficient water quality indicator in that it provides no information on the state of eutrophication and the possibility of algal blooms.

The application of modern waste treatment technology demands decisions on the removal of inorganic nutrients, in addition to the conventional removal of oxygen-demanding organic materials. The questions of what to remove and how much to remove are fundamental to intelligent design and investment decisions on the treatment of wastes prior to discharge into an adjacent river or estuary. These questions can only be answered by water quality models that are capable of predicting the ecological response of the waterway to increased levels of treatment. It is clear that future research efforts in water quality modeling and field data collection should be directed to the modeling of transformation processes within the element cycles of an aquatic ecosystem.

TRANSFORMATION PROCESSES NUTRIENT MODELS

Current efforts in water quality modeling are attempting to deal with problems of eutrophication by assuming that aquatic ecosystems are composed of coupled conservation of mass equations (Quinlan).[7] A one-dimensional, real-time, biogeochemical model for an aerobic, nitrogen-limited estuarine ecosystem subject to domestic sewage loadings has been developed by Najarian.[8] The proposed estuarine water quality model attempts to follow the path taken by nitrogenous nutrients (in their various forms) based on the present knowledge of element cycles in aquatic ecosystems. In contrast to the simple CBOD - DO model, the nitrogen model represents various forms of organic and inorganic nitrogen which are the potential sources of eutrophic activity.

The dynamic estuarine nitrogen cycle model consists of a closed matter flow loop having seven storage variables and twelve transformations of the element nitrogen from one storage form to another as shown in Figure 1. The chosen storage and transformation processes represent physical, chemical, and biological forms of nitrogen. The hypothesized structure of the model is sophisticated enough to simulate nitrogen-limited ecosystem dynamics, yet it is simple enough to be amenable to computations. The seven storage variables include ammonia-N, nitrite-N, nitrate-N, phytoplankton-N, zooplankton-N, particulate organic-N, and dissolved organic-N. The biochemical and ecological transformations include nitrification, uptake of inorganic nutrients by autotrophs, grazing of heterotrophs, ammonia regeneration by living cells, lysis and leakage of organic matter through cell walls, natural death of microorganisms and ammonification. The transformation rates are functions of nutrient concentrations and available energy in the form of heat and light.

To explore the dynamics of the closed nitrogen element cycle the proposed seven variable model is applied to the batch or chemostat system shown in

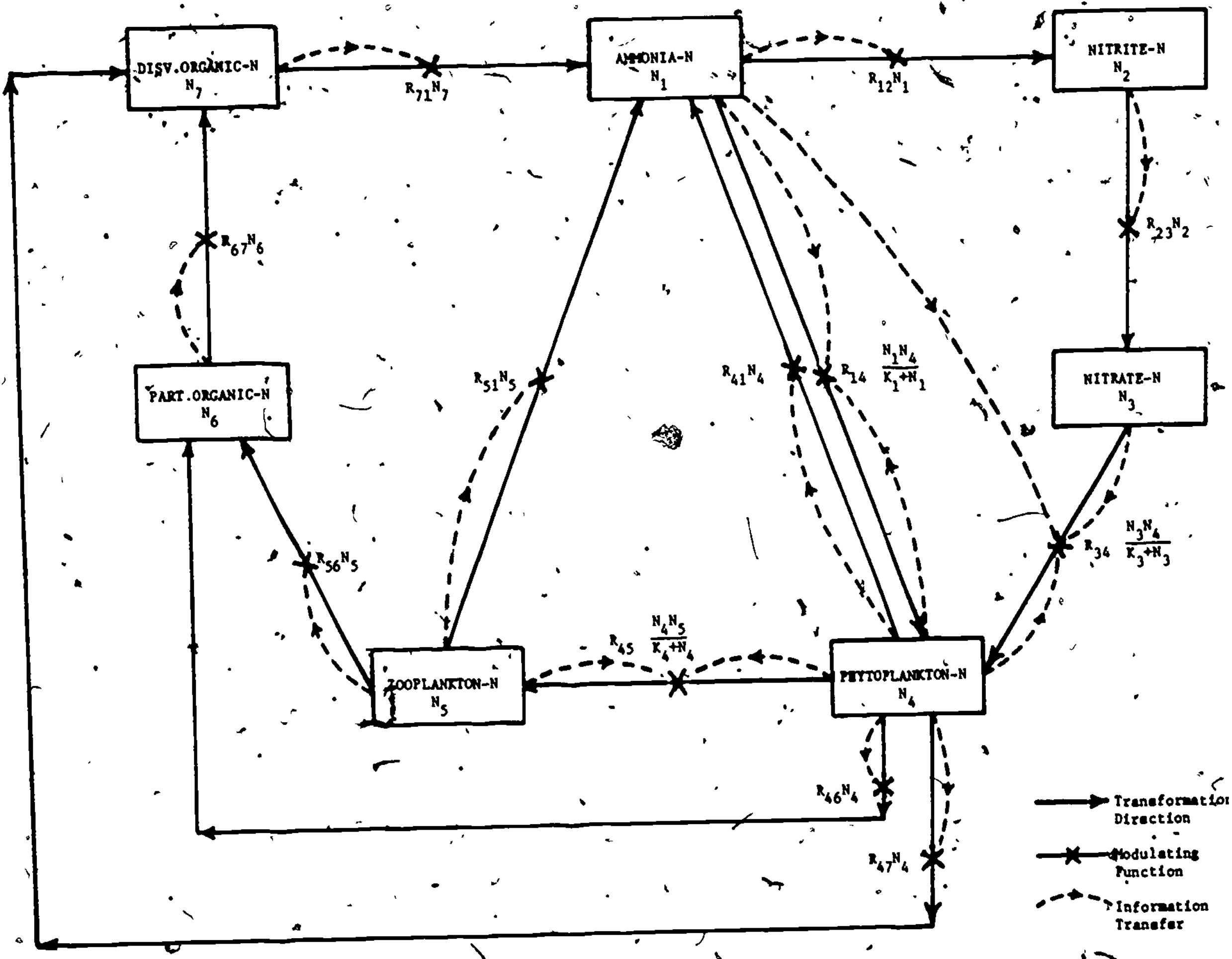

FIGURE 1.—Nitrogen: cycle structure in aerobic aquatic ecosystems.

Figure 2. The set of seven mass conserv[illegible] equations for the chemostat, obtained from equation (3) (with $\partial C/\partial x = 0$) are listed below. The assumed expressions for each of the transformation rates are shown on the solid arrows in Figure 1. The dotted lines indicate the information transfer necessary to determine the rates of matter flows.

$$\frac{dN_1}{dt} = R_{41}N_4 + R_{51}N_5 + R_{71}N_7 - R_{12}N_1 - R_{14}\frac{N_1N_4}{K_1+N_1} + (Q/V)(N^\circ_1 - N_1) \tag{8}$$

$$\frac{dN_2}{dt} = R_{12}N_1 - R_{23}N_2 + (Q/V)(N^\circ_2 - N_2) \tag{9}$$

$$\frac{dN_3}{dt} = R_{23}N_2 - R_{34}\frac{N_3N_4}{K_3+N_3} + (Q/V)(N^\circ_3 - N_3) \tag{10}$$

$$\frac{dN_4}{dt} = R_{14}\frac{N_1N_4}{K_1+N_1} + R_{34}\frac{N_3N_4}{K_3+N_3} - R_{45}\frac{N_4N_5}{K_4+N_4} - (R_{41} + R_{46} + R_{47})N_4 - (Q/V)(N^\circ_4 - N_4) \tag{11}$$

$$\frac{dN_5}{dt} = R_{45}\frac{N_4N_5}{K_4+N_4} - (R_{56} + R_{51})N_5 - (Q/V)(N^\circ_5 - N_5) \tag{12}$$

$$\frac{dN_6}{dt} = R_{46}N_4 + R_{56}N_5 - R_{67}N_6 + (Q/V)(N^\circ_6 - N_6) \tag{13}$$

$$\frac{dN_7}{dt} = R_{47}N_4 + R_{67}N_6 - R_{71}N_7 + (Q/V)(N^\circ_7 - N_7) \tag{14}$$

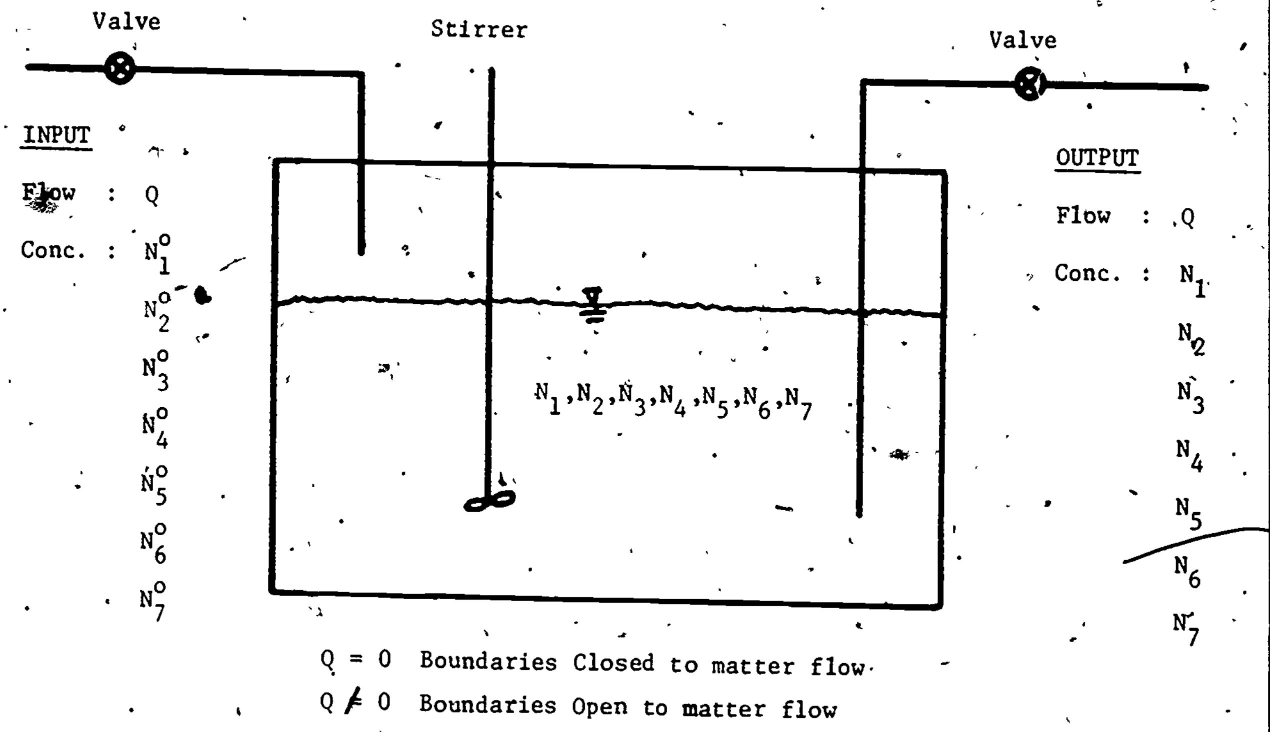

FIGURE 2.—Batch and chemostat systems.

where

N_1 = concentration of $NH_3 - N$, mg/1
N_2 = concentration of $NO_2 - N$, mg/1
N_3 = concentration of $NO_3 - N$, mg/1
N_4 = concentration of phytoplankton-N, mg/1
N_5 = concentration of zooplankton-N, mg/1
N_6 = concentration of particulate organic-N, mg/1
N_7 = concentration of dissolved organic-N, mg/1
N^o_i = concentration of ith nitrogen-cycle storage variable in the influent discharge, mg/1 ($i = 1,2, \ldots 7$)
K_1 = half saturation constant for NH_3-N, mg/1
K_3 = half saturation constant for NO_3-N, mg/1
K_4 = half saturation constant for phyto.-N, mg/1
R_{ij} = transformation rate from ith storage variable to jth storage variable, 1/day
Q = rate of inflow and/or outflow, ft^3/day
V = volume of the container, ft^3

Equations (8) - (14) are applicable to batch and chemostat systems. However, the external source terms $(Q/V)(N^o_i - N_i)$ are zero in batch systems. The analysis of the system equations reveals that the formulated structure of the nitrogen-cycle model is a closed matter flow loop with no leaks. Indeed, for every positive internal source term there exists an identical negative internal sink term in the set of system equations. This reciprocity of the source/sink terms is in accord with the principle of mass conservation applied to a closed-loop element cycle.

The expressions which describe the rate of transformation processes are of two types: first order reaction kinetics in the form of $\frac{dN_j}{dt} = R_{ij}N_i$ or saturation kinetics in the form of a hyperbolic expression $\frac{dN_i}{dt} = R_{ij}\frac{N_i N_j}{K_i + N_i}$. Data in the literature show that transformation rates that relate to nutrient uptake by primary producers or predators usually follow saturation kinetics. These process rates are all temperature-dependent. Uptake rates also vary with the intensity of solar radiation.

BATCH SYSTEM

The response behavior of the nitrogen cycle in a batch system is determined by (a) the initial concentrations of the storage variables and, (b) the assumed transformation rate parameters. At all times the total amount of nitrogen in the system is equal to the sum of initial concentrations of elemental nitrogen in its various storages, i.e.,

$$\sum_{i=1}^{7} N_i(t) = \sum_{i=1}^{7} N_i^{in} \qquad (15)$$

where N_i = concentrations of nitrogen-cycle storage variables at any time t, mg/1
N_i^{in} = initial concentrations of nitrogen-cycle storage variables at time t=0, mg/1

The constraint equation (15) implies that the Q term in the system governing equations is equal to zero.

The response analysis of the nitrogen model in a batch system is shown in Figure 3. The analysis reveals that the structured model exhibits a limit-cycle behavior. Such a behavior is characterized by inherent undamped oscillations in the cycle. These sustained oscillations are the result of the assumed hyperbolic expressions for the uptake of nutrients by the biota. Quinlan (1975) discusses in detail the response characteristics of structures that assume quadratic or linear expressions for ecological process rates. Rate-governing parameters used in equations (8) - (14) are given in Table 2. These values are within the range of values reported in the literature.

Table 2.—Transformation rate parameters.

R_{12} = 0.20/day
R_{14} = 2.0/day (light hours); 0.10 (dark hours)
R_{23} = 0.25/day
R_{34} = 1.0/day (light hours); 0.05 (dark hours)
R_{41} = 0.01/day
R_{45} = 0.07/day (light hours); 1.50 (dark hours)
R_{46} = 0.03/day
R_{47} = 0.03/day
R_{51} = 0.01/day
R_{56} = 0.10/day
R_{67} = 0.30/day
R_{71} = 0.30/day
K_1 = 0.3 ppm-N
K_3 = 0.7 ppm-N
K_4 = 0.5 ppm-N

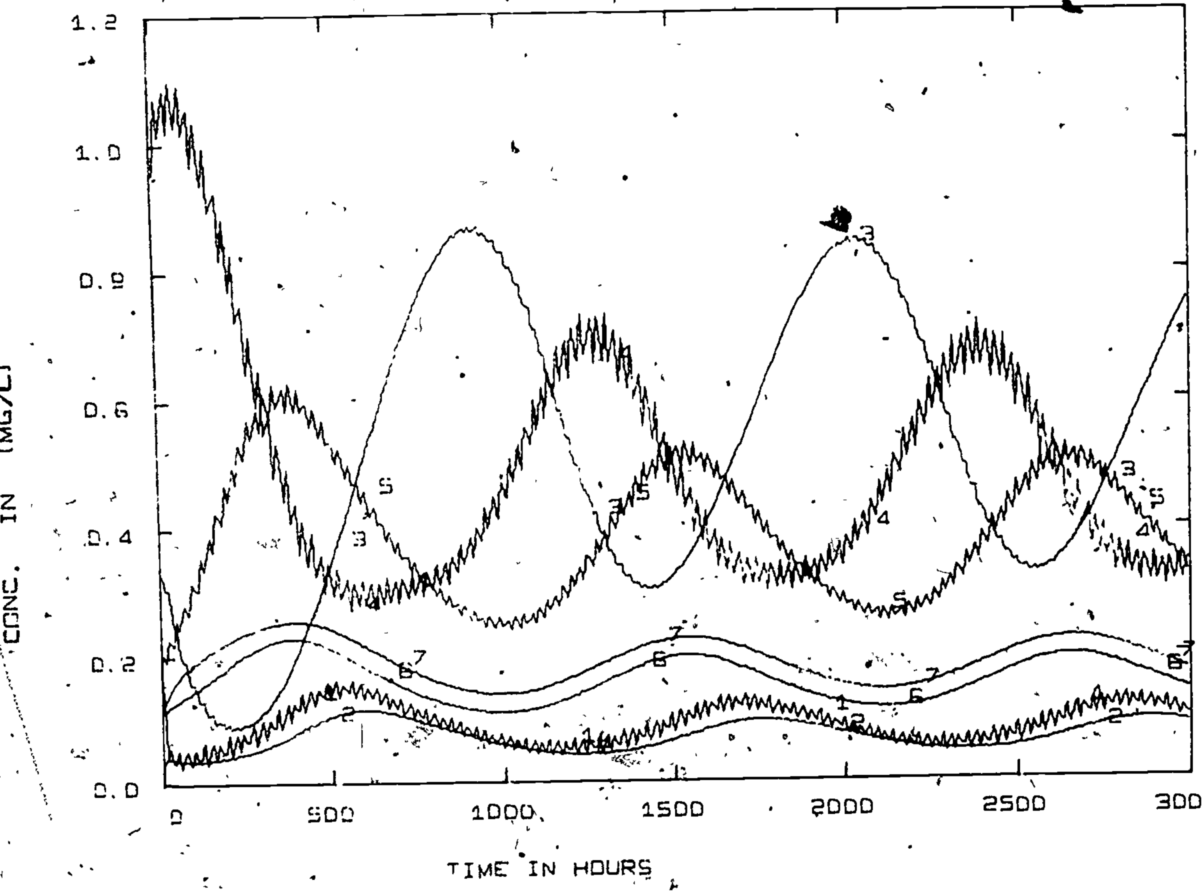

FIGURE 3.—Limit-cycle response of a batch system with closed boundaries (Q = 0) (1-NH_3-N; 2-NO_2-N; 3-NO_3-N; 4-Phyto-N; 5-Zoopl-N; 6-Part. Organic-N; 7-Disv. Organic-N).

CHEMOSTAT SYSTEM

Figure 2 shows the chemostat system with mass transfer across the physical boundaries of the system. The mass conservation principle requires that the following constraint equation be satisfied:

$$\sum_{i=1}^{7} N_i(t) = \sum_{i=1}^{7} N_i^{in} + \int_0^t \sum_{i=1}^{7} [N_i^{\circ} - N_i(t)] \frac{Q}{V} dt \qquad (16)$$

The response analysis of the nitrogen cycle in a chemostat system is shown in Figures 4 and 5. These analyses reveal additional system structure characteristics:

(i) When elemental nitrogen in one or more of its storage forms is continuously added and removed from the chemostat, the limit-cycle behavior disappears and a damped oscillation develops. Figure 4 shows the response of the chemostat with identical system rate transformation parameters as for the batch system shown in Figure 3. The residence time of the system is assumed to be 15 days, i.e., V/Q = 15.

(ii) The forced damping of the chemostat system oscillations is dependent on the magnitude of the assumed modulating parameters. If the half saturation concentrations K_1, K_3 and K_4 are reduced to 50 percent of their originally assumed values, a new dynamic response of the system is observed as shown in Figure 5.

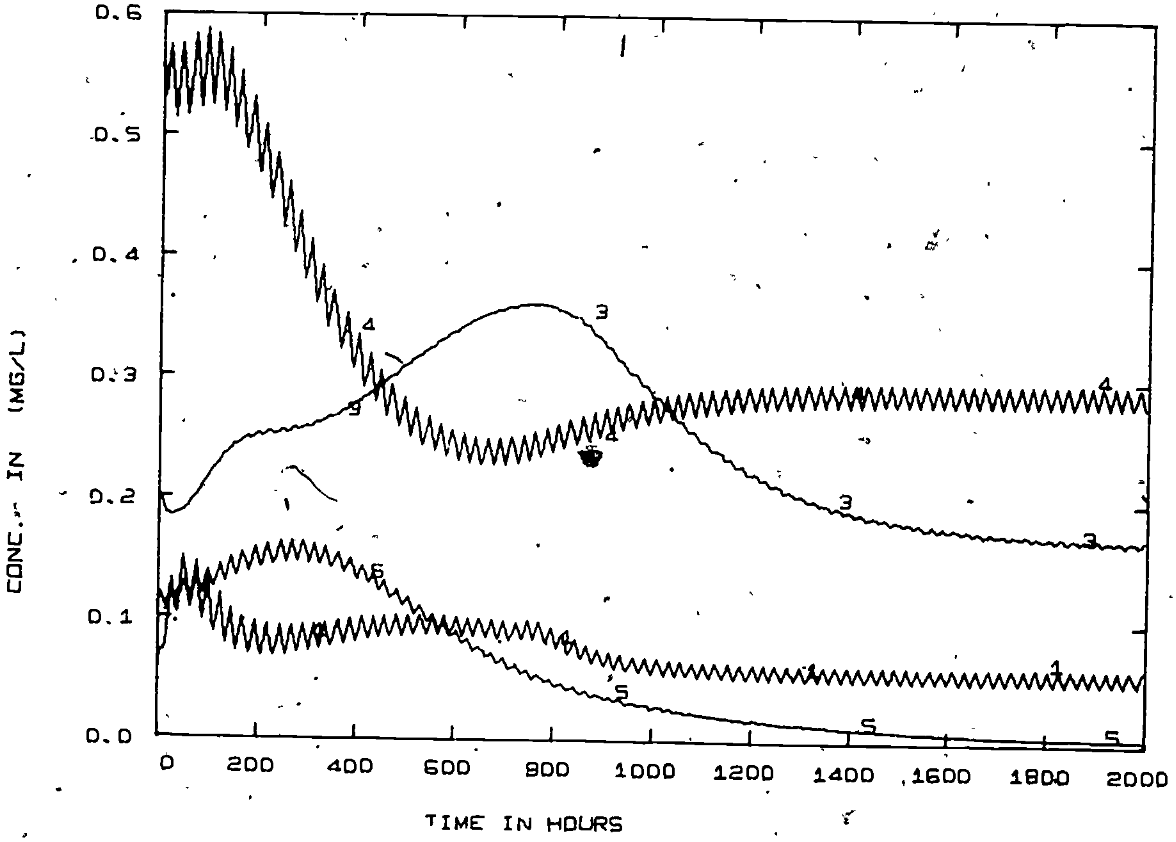

FIGURE 4.—Dynamic response of a chemostat system with open boundaries (1-NH_3-N; 3-NO_3-N; 4-Phyto-N; 5-Zoopl-N); $K_1 = 0.3$; $K_3 = 0.7$; $K_4 = 0.5$.

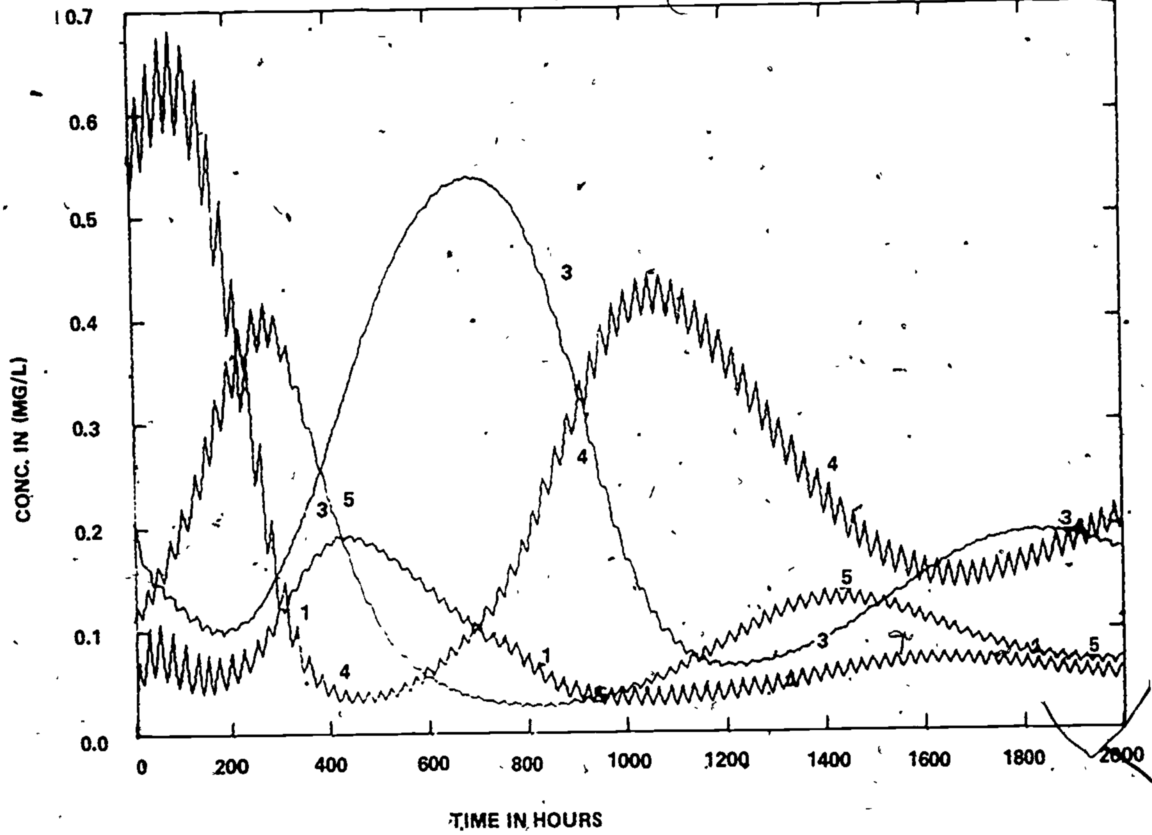

FIGURE 5.—Dynamic response of a chemostat system with open boundaries (1-NH_3-N; 3-NO_3-N; 4-Phyto-N; 5-Zoopl-N); $K_1 = 0.15$; $K_3 = 0.35$; $K_4 = 0.25$.

POTOMAC ESTUARY

The most dramatic evidence of the effect of physical factors on water quality comes from the application of the nitrogen cycle model to an actual estuary. The tidal motion and longitudinal mixing processes in an estuary are highly variable both in time and space; in addition, the diurnal light-dark cycle is out of phase with the lunar tidal cycle. Najarian and Harleman[8] have demonstrated the application of the nitrogen cycle model to the Potomac Estuary from the head of the tide near Chain Bridge to the junction with Chesapeake Bay, a distance of 114 miles. A period of 19 tidal cycles (about 10 days) was chosen for the simulation run. Waste treatment plant loadings in the upper 30 miles of the estuary were included, the major contribution being the Blue Plains waste treatment facility. The model calculates the tidal motion by means of the continuity and momentum equations, (1) and (2). Temperature and salinity can be determined from equations (4) and (5) and coupled to the seven nitrogen conservation of mass equations in the form of equation (3). Time steps of the order of 30 minutes were used for the calculations with spatial increments ranging from 1,000 to 10,000 feet in length.

Time histories of the seven nitrogen variables during the 10-day run are shown in Figures 6, 7, and 8 at a location 2 miles below the Blue Plains waste treatment facility. Of interest is the large variability of many of the water quality parameters within a tidal period. This characteristic, which results from a coupling of the hydrodynamic transport and the biochemical transformations, suggests that a re-evaluation of traditional estuarine field data collection techniques is necessary. More attention must be given to determining the temporal variations of constituents at fixed locations.

Obviously much more is known about hydrodynamic transport processes than is known about biochemical processes. Because of this it is important that water quality models incorporate correct transport processes so as to avoid obscuring further understanding of the complex biochemical transformations.

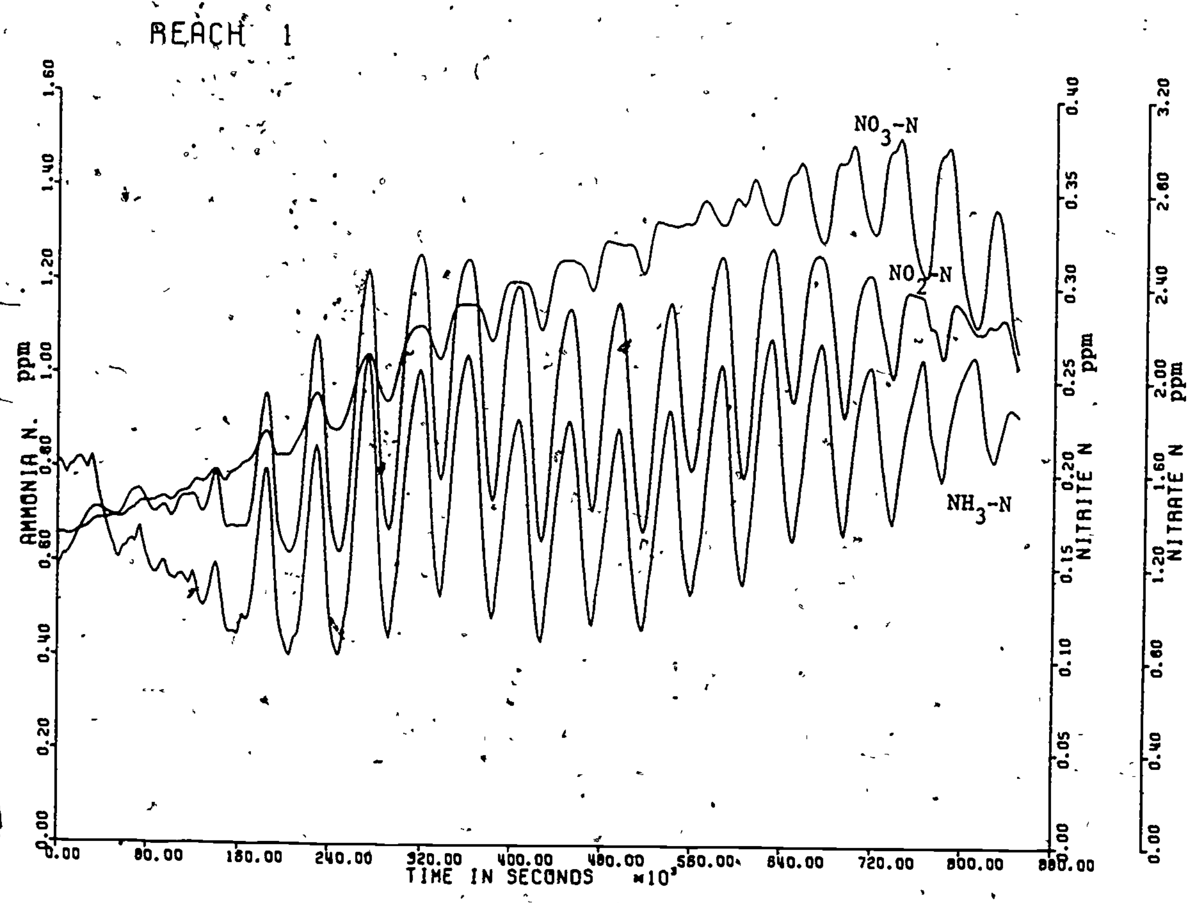

FIGURE 6.—NH_3-N, NO_2-N and NO_3-N variations 2 miles downstream of Blue Plains, July 15-24, 1969.

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DISCUSSION

Chairman Ballentine: Who prepared the biochemical models that you presented here? Is this another member of your team at MIT?

Dr. Harleman: Yes. I'm very sorry that I didn't verbally acknowledge the important contribution of two of my students. Dr. Alician Quinlan did much of

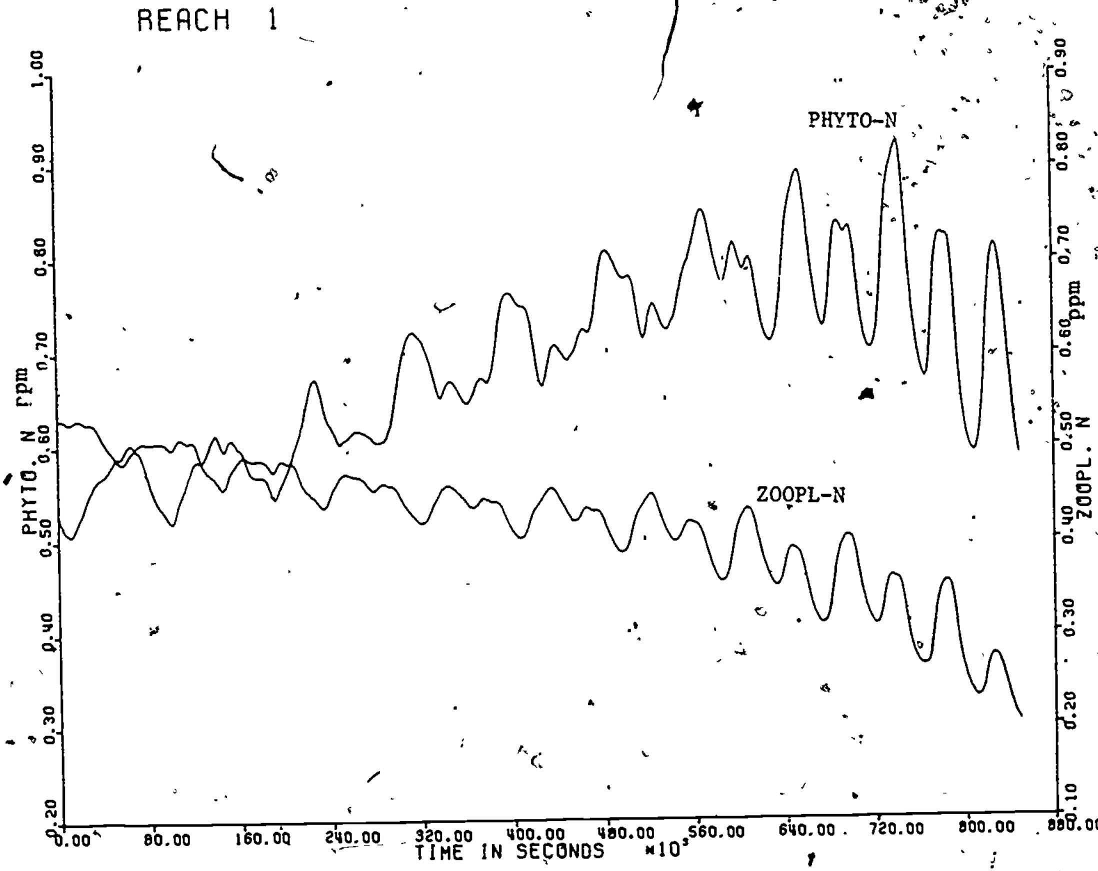

FIGURE 7.—Phyto-N and Zoopl-N variations 2 miles downstream of Blue Plains, July 15-24, 1969.

the fundamental work relating to the structure of this type of modeling and the sensitivity and system responses as a function of the parameter relationships.

Another student, Tavit Najarian, has taken this general structure and applied it to some of the estuarine processes that I have shown. They are both Ph.D. theses and are available as technical reports of the Ralph M. Parsons Laboratory at MIT.

Chairman Ballentine: You made some comments concerning the problems of monitoring. From a practical viewpoint, do you believe that, for instance, slack water type monitoring is still superior to other types, or what would you suggest?

Dr. Harleman: I would prefer to see a much more concentrated effort at looking at the time variability of parameters at fixed locations. I would be willing to accept a more limited spatial distribution in favor of temporal definition. Observations at fixed locations should be made at least during a tidal cycle; from one slack to the next. I would very much like to see and encourage the approach of looking at the variability at fixed stations, because I do not think it possible in these nonlinear systems to account for these effects by translation or other approximations of the tidal flow. When you put the same rate constants into the biochemical models and approximate the flow by a freshwater discharge which eliminates the tidal reversals, the results are quite different.

So that if you fit the data you would end up with different fitting constants, but it's the same process going on.

Chairman Ballentine: Just to foster some discussion here, I know that much of Dr. O'Connor's data in New York Harbor were collected by the Department of Public Works. They would get their boat out once a day and go down the river and collect samples in a grab fashion. Is that correct?

Dr. O'Connor: Yes.

Chairman Ballentine: So you have to work pretty much with average values?

Dr. O'Connor: Yes. On the New York Harbor we did that over a good portion of the summer period when the assumed studies existed, so they did that maybe for 2 or 3 months for a recent study hydrograph of the Hudson. They took various points in

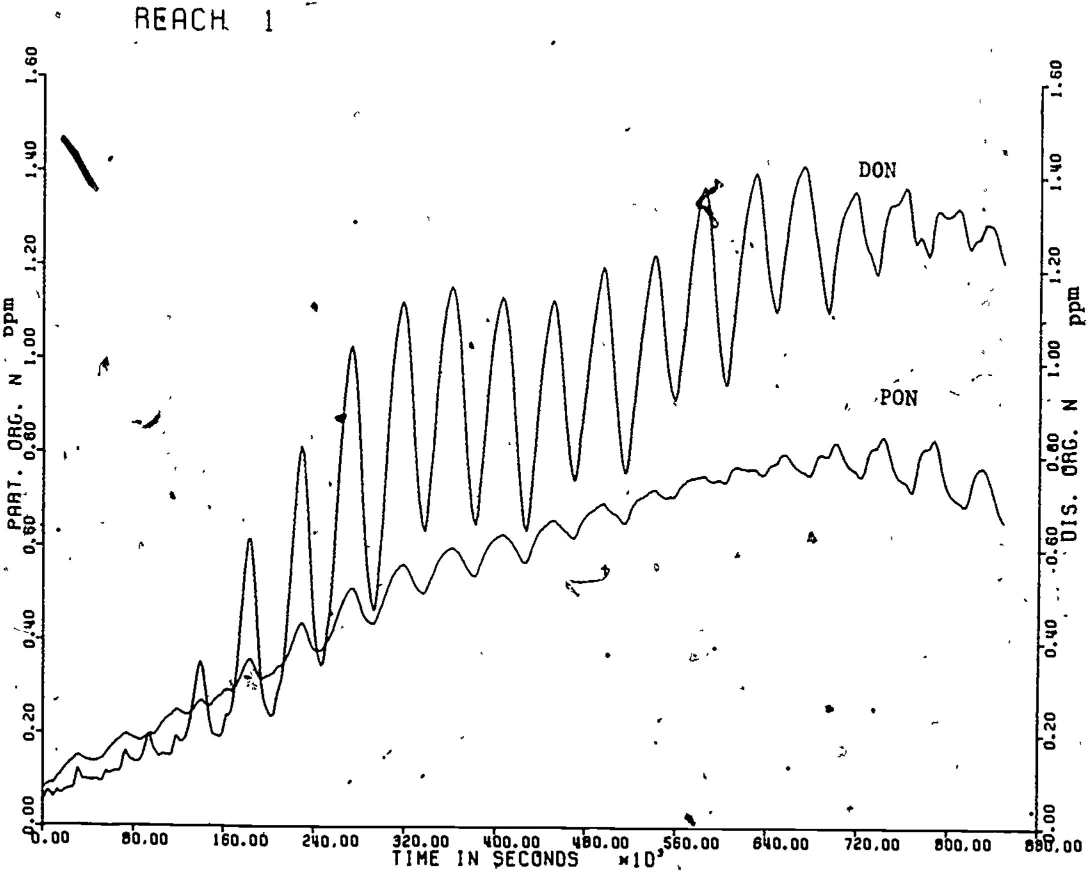

FIGURE 8.—Part. Organic-N and Dissolved Organic-N at 2 miles downstream of Blue Plains. July 15-24, 1969.

the tidal curve by doing a random collection. So, I assume the average there was a mean-tide condition.

I have mixed feelings about Dr. Harleman's suggestion. I'll just make one point. I certainly see what you're getting at, but I'd like to look at that more critically.

My greatest concern, of course, is the practical impact this has on collecting field data. I think we're getting overloaded in what we're asking for, and now we're asking for additional data, which might start to break the back, so to speak.

Dr. Harleman: I'm not necessarily asking for additional data. Spend the same amount of money on collecting data and give up the practice of running a boat up and down the estuary. Concentrate on a smaller number of spatial points, but more detailed coverage in time.

Dr. O'Connor: It's getting back to the old problem. It's a two- or three-dimensional time variable problem, so it depends on how one looks at it, or what one abstracts from it; it depends on what way he thinks is most meaningful to look at.

Chairman Ballentine: Is this one of the oceanographic approaches where they sit on station?

Dr. O'Connor: Yes. By contrast to what we had.

Chairman Ballentine: This is where you race the slack upstream?

Dr. O'Connor: Yes.

CHANNELIZATION

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Through the medium of this symposium, we are all asked to assist the Environmental Protection Agency in ". . . defining the concept of water integrity in its various forms." The stated ". . . purpose of the Symposium is to address the issues required by Section 304(a) (2) (A) and (B)" which, I believe, really means addressing the issue posed by the policy declaration of Section 101 of the Act, since Section 304 neither requires nor poses an issue; but rather seeks information. Further, each presenter is requested to address the problem associated with his topic, drawing upon his background and perspective.

For my assigned topic—the one word channelization—no other guidance by the EPA was offered as to how I should handle it. This is commendable, of course, but with the latitude it provides me goes a special responsibility. Certainly it has been an issue, certainly a problem as well, But the two terms, issue and problem, are often used interchangeably and inaccurately. In my research background, and in discussing research assignments with others, I have frequently found it necessary to call attention to an important difference between the two terms.

Research seeks or ought to seek, the solution to a problem and is, or should be, detached from processes for the resolution of issues. If it is not so detached, research is inescapably drawn into taking a position on a question, often a vital question for debate—which defines an issue. It is therefore not research and should go by another name. Still, research may illuminate an issue and contribute to its resolution by placing the problem in perspective. I intend to keep my remarks problem-oriented, which is to say subordinate to other perfectly valid—indeed essential—processes in a democratic society.

As for the meaning of "the integrity of water," I have heard it expressed variously here in the past 24 hours. For example, "only pristine waters possess integrity"; "integral systems—good or bad—whatever the changing state over time"; "background condition as a reference point"; and "not a concept meaning return to a previous state." I have also heard "try to improve it, but at least keep it the way you find it"—which is really more an approach than a definition. Finally, it is said to be a philosophical and moral question.

Setting aside these concepts for the moment, I would pose four questions, attempt to provide some answers, then return to the concept of integrity and try to relate it to channelization.

The four questions are: (1) What exactly is channelization? (2) What has been the extent of its applications? (3) What have been its observed physical effects on navigable waters, ground water, waters of the contiguous zone, and the oceans? (4) What have been its observed physical effects on fish and wildlife and on recreational activities?

The inclusive term channelization—sometimes called channel improvement, alteration, or modification—can mean variously the straightening, widening, deepening, lining, clearing, dredging, re-directing, creating, or re-creating of watercourses. These are all essentially hydraulic engineering techniques that can be applied singly or in combinations, together or in tandem, in moderate or substantial scale. All are more or less self-explanatory, but there are differences or degrees of application.

Straightening a watercourse, for example, may involve slight realignment of a single curvature or pronounced departure from the course of flow at an upstream point to reconnection several miles downstream—sometimes called a "floodway." Widening or deepening a natural alignment may increase cross-sectional dimensions by 2 or 3 feet to 100 feet or more. Lining, if any, may be with grass-type vegetation, often producing what is called a "grassed spillway," by gravel, rock-emplaced rip-rapping, bank stabilizing revetments of steel or timber, or poured concrete; all of a trapezoidal design configuration to smooth channel beds and provide channel banks of varying slope, from vertical to relatively horizontal. Such designs often provide a "notched" channel bed or "pilot" channel intended to maintain very low but continuous flows within a confined trough of the larger channel dimensions.

Clearing, snagging, or dredging is designed to remove obstructions to flow in the watercourse.

This can mean the cutting of trees and brush from channel beds and banks, and sometimes from a wide right-of-way on either side as well, to accommodate placement and spreading of excavated [illegible] dredged "spoil" material. Early works neither spread nor reseeded spoil banks. More recently, where dredged material is a problem, rights-of-way have been contoured and quickly revegetated. The removal of sediment, sand or gravel bars, large boulders, timber, constricting bridges, and old dams is another feature of clearing.

Redirecting or creating a new watercourse may involve the placement of jacks or jetty fields to induce the aggradation or deposition of sedimentary materials in desired configurations—again, to alter flow patterns similar to moderate straightening. Natural stream flow then does the work of channel alteration. It may, however, involve cutting an entirely new watercourse from an upstream point of departure to an entirely different outlet, such as in a lake or estuary. This is sometimes called a "cut-off." Finally, re-creating a watercourse may mean restoring the flow capacity to either a partially or totally clogged drainage ditch or canal, usually occasioned by poor original design relative to soil conditions or to poor maintenance of complete works resulting in heavy siltation and vegetation.

The building of levees in flood plains some distance away from the normal channel alignment—which is left physically undisturbed—is a form of channelization, as is the stair-step series of low dams and locks which provide shallow draft commercial or recreational navigation. Levees infrequently cause flow alteration, while navigation systems constitute essentially permanent alteration to the flow regime. Neither is customarily grouped within the popular term "channelization." The recent EPA guidelines give navigational channeling the prominence it deserves, but which has long been neglected.

The extent of the applications of these several techniques is extremely variable, geographically, and by watercourse. Taking the broadest view and bearing in mind the integrity of water definition, it can be said that the major arteries of the vast Mississippi drainage system have been channelized—from New Orleans to Knoxville, Tenn., to Pittsburgh and beyond, to Chicago, to Minneapolis, to Sioux City, Iowa, and to the border of Oklahoma, touching or reaching into 19 states in one continuous system. Except where only "maintenance dredging" is carried out on the lower Missouri and Mississippi Rivers, all of this type of channelization constitutes permanent impairment, a point of no return, decidedly not in "correspondence with an original condition."

This is an extreme view, to be sure. At the other extreme, statistical data as of mid-1971 (and it seems unlikely that the data are markedly different now), reveal that the average—or I might say typical—application has been in combinations of straightening, widening, deepening, clearing, and lining of 5.2-mile segments of minor tributary streams, brooks, and unnamed legal or county drains, typically small watercourses with perennial, intermittent seasonal, or no measurable flow patterns. I say average or typical based upon a statistical analysis of 1,630 completed and planned applications classified by the unfortunate term "channel improvements." My average derives from 6,969 miles of completed works. About 20,000 miles of additional works—20,000 additional linear miles—were planned at that time. The median project size for completed and planned applications was about 4 miles. More than 80 percent of completed works were concentrated in 10 southern states.

Let me hasten to add—lest it appear that I am implying a physical significance to some programs that have received little attention and a physical insignificance to others that have received much attention, that between these extremes there have been important and widespread applications of channelization to larger watercourses and legally-defined navigable waters. I cite the extremes in the context of our deliberations on the concept of integrity of water. If, as a practical matter, the legislative interest cannot be allowed to extend to restoring and maintaining the unimpaired and unmarred integrity of some 3,700 miles of the impounded Mississippi transportation system, can this legislative interest logically extend, again as a practical matter, to additional thousands of miles of unnamed tributaries and local "court," "county," legal, or "district" drains, the rehabilitation of which constitutes a sizable portion of channelization applications? In my own rather thorough study of 2,300 miles of channel modifications selected for me to study as a more or less random but representative sample, I found that in 48.8 percent of the cases a combination of techniques was applied to drainage ditch rehabilitation.

Turning to the third and fourth of my questions, the situations between the extremes just described have been the most studied and observed and are the most revealing of physical effects. Again, I would hasten to add that, without question, all situations demonstrate some physical changes that bear in some way on the integrity of water concept.

Two comments to the physical effects questions seem in order. First, you may have observed that I have thus far used the term "watercourse" when I might have said stream or river. This was deliberate—to distinguish natural water systems, on the one hand, from those water systems, on the other, that have not been natural or untouched for a long time and, indeed, those that did not exist before one or more of the applications described came about. I suppose that, in terms of our integrity inquiry here, the questions this distinction raises are: how far does navigability extend and how is the contiguous zone defined?

The second comment: it is very difficult to distinguish where physical effects leave off and chemical and biological effects come into the picture. Where is the dividing line or transition point? Dr. Patrick and I had occasion to wrestle over this question—figuratively speaking, of course—when we were trying to sort out our respective responsibilities on an assignment for the CEQ some time ago. I will try to observe here the distinctions drawn at that time. Thus, I will deal with (1) rates of flow, (2) volumes of flow, (3) contents of flow, (4) distances, (5) temperatures, (6) light, and (7) habitat.

One could visualize a three-dimensional matrix which would portray the relationships between these physical factors against (a) those types of applications—clearing, realigning, and so forth, described earlier, and (b) those popularized but complex effects called wetland drainage, cut-off meanders, groundwater diminution and recharge, erosion and sedimentation, downstream effects, and aesthetic values. Such a portrayal is quite impossible to present in an organized fashion.

Instead, suppose we hypothesize a typical situation between the water system extremes that I have described. Say it's a 30-mile channeling job to a natural stream whose integrity or virginity has not yet been surrendered or compromised, so to speak. Say further that the stream has some perennial flow (not a normally dry creek bed), a varied bankside habitat (not a terrestrial system devoid of vegetation), and a "natural" quality of water (not a biologically dead or grossly polluted aquatic habitat). Say further that the intended purposes of this job are to drain excessively wet but potentially productive farm lands in upper reaches and to protect an urban community against flood waters in lower reaches. Say, finally, that some of all the applications of techniques of channelization are to be carried out. What effects may be expected with some assurance?

The answers can be quite brief and will come as no surprise. There are surprises once one begins to deal with the data relative to the idealized model against which you're testing the data. First, the clearing, snagging, and removal of bankside vegetation and instream obstructions from an upstream segment will tend to increase both the volume and rate of streamflow, for a number of reasons, including reduced evapo-transpiration, higher surface runoff, freer flow conveyance passage, higher groundwater transmissibility rates, and more rapid snow melt. At the same time, higher volumes will tend to increase bank storage of ground water. Contents of the flow will be altered in at least two ways—more suspended sediments due to higher surface runoff rates but less oxygen-demanding biodegradable or "background" material entering the water from leaves and other droppings. Water temperatures will be raised by the direct rays of the sun (there's less canopy over the water from trees), but lowered by the entry of more ground water. More light on the water will alter photosynthetic processes, but perhaps unpredictably. Terrestrial habitat for species that seek trees and wet ground will be reduced; that for species seeking brush, grasses, and dry ground will be increased. Aquatic species seeking pools, riffles, and shade will find less of such habitat; those species seeking warmer waters, more oxygen, and freer passage upstream will find these.

Next, the widening, deepening, and straightening of a middle segment of this natural stream (which, incidentally, will require similar clearing, snagging, and removal of obstruction but in larger dimensions and to accommodate construction activities) will have those effects described above and others. Rates and volumes of flow will increase further; waters will contain more suspended material and some will deposit as bed-load sand bars despite higher velocities generally; temperatures and light intensity will rise further; and there will be less of some kinds of habitat favored by some terrestrial and aquatic species and more of other kinds favored by other species. Moreover, as soil conditions are found to be unusually erosive in this hypothesized instance, graveled and rip-rapped bank stabilization in parts of the segment will leave no habitat. In other parts, moderately sloped banks will prove too steep to allow reseeding immediately to take root during heavy rains. As a result, sedimentation is traced downstream beyond the 30-mile project, despite in-channel drop or stabilization structures. A more pronounced physical effect occurs when a wide-sweeping meander or oxbow is cut off by a straight channel section. While intended that the cut-off natural channel is to continue to receive and pass flows, and its bankside habitat is untouched, the aggraded sediment and channel scour will conspire to plug the entrance to and exit from the oxbow and to reduce the new channel bed's elevation below the oxbow channel bed's elevation. Thus, a stagnant pool or bayou will be created.

Next, the flow conveyance capacity in a third segment, below that just described, must be maintained as designed by a concrete-lined channel with vertical sides and flat bottom, except for a notched passageway in the bed. This is occasioned by a constricted right-of-way through the urban area. The alignment is not altered, only the cross-sectional dimensions are widened and deepened. Also, no clearing is necessary, as no vegetation is present to clear. The channel is bounded on one side by a railroad, on the other side by a street fronting assorted factory and warehouse buildings in varying stages of deterioration. The stream gradient flattens out from the steeper upstream gradient of the valley. A partially washed-out mill dam, behind which is a century's accumulation of assorted sludge, is to be removed. The effects here will be substantially increased rates and volumes of flow, a reduced concentration of suspended materials, no change in temperature, light, or terrestrial habitat, and a total change in aquatic habitat from mixed sludges, oils, and chemicals to solid concrete. A chain link fence will bound the channel, atop the retaining wall, on both sides. Drain pipes will be designed to maintain ground water in the contiguous zone at pre-project levels.

Finally, just downstream of the channel job, the natural stream enters the headwaters of a large reservoir created by a dam 20 miles farther downstream. Storage and release operations of the reservoir occasion daily and seasonal drawdowns, with fluctuations of up to 4 feet daily and 40 feet seasonally. Waterfowl abound in the headwaters region and sport fishing conditions are excellent. The downstream effects of the channel job are also predictable. To the extent that upstream changes are experienced, i.e., increase in volume of flow, erosion and transport of suspended materials, and higher temperatures, these will be transferred to the lower reservoir. Rates of flow will drop to zero, light will be unchanged, and terrestrial habitat will remain unaltered. Sediment deposition in the reservoir will totally alter lake bottom aquatic habitat important to the fishery in the upper reservoir reaches.

What I have described is a composite channeling job in the sense that virtually all of the techniques are to be applied and to a fairly broad range of pre-project conditions or environmental settings. But it is more than that. It is in fact a set of applications and settings which I observed and studied on one completed project in the field, the physical effects of which I attempted to evaluate.

For our purposes here, however, the description is incomplete, not so much in the recording of applications of techniques, but in the portrayal of the range of settings in which they have been applied elsewhere. One could correct this by substituting a number of descriptive phrases. These would range from richly varied swamp forest ecosystems, through rolling prairie and high-country farm lands, to barren and semi-arid range lands. The soil conditions could range from highly erosive to bedrock ledge. The downstream receiving waters could be a natural lake, swamp, inland river, coastal stream, or estuary.

The descriptions are also incomplete in two different ways: Namely, the effects over time and the cumulative effects, which I feel have been substantially ignored.

By cumulative I mean not necessarily upstream-downstream, but cumulative in the sense that these channeling applications may occur in 8 or 10 or 20 projects in the same river basin and they all converge on the downstream outlet.

Clearly, whenever a natural stream system is tampered with a new ecosystem confronts the fish and wildlife species that inhabit it and new associations must be set in motion and established. Whether these are destructive or enhancing events can only be defined in terms of individual or group objectives. For example, it is one thing to describe a physical event stemming from channelization as a diminished rate of groundwater accretion or a loss of seasonal overflow to flood plain wetlands. These and other things do happen. It is another thing to record the induced changes to species numbers, productivity, and diversity. It is still another to assert that these happenings are always good or always bad.

When it comes to the third in this progression of determinations, we enter the arena of policy, both legislative and administrative. I could suggest elements of administrative policy in the following manner. In the total water and related land system, from forested or arid uplands through waters of the contiguous zone and navigable rivers to estuaries and the oceans, channelization seems at first not to jeopardize the integrity of waters, then to jeopardize it severely, and then again not to do so as effects are dampened out in larger systems. In the long process of hammering out administrative policy there is, I am advised, evidence of a willingness to accept the validity of drainage needs. There is also, I know from very recent experience, a similar tolerance or willingness to accept the validity of nonstructural flood plain management devices in lieu of structural means to convey floodwaters. Both are healthy and constructive signs.

Still, administrative policy development seems confronted with a dilemma posed by legislative policy. One declares a national policy—". . . . to restore and maintain the physical, chemical and biological integrity of the . . . waters" (Sec. 101, P.L. 92-500) and this is prompted by frustrations and impatience with two decades of disappointing water quality program performance. This declaration followed closely on the heels of another national policy—". . . . to use all practicable means and measures . . . in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic and other requirements of present and future generations of Americans" (Sec. 101(a), P.L. 91-190).

These two policy pronouncements seem to converge with inconsistency on the channelization question. Perhaps, as a practical matter, the concept of nondegradation may need to replace the concept of integrity if the deliberations here are to produce sound and equitable results.

DISCUSSION

Comment: Can Mr. Wilkinson detail the nature of the controversy, briefly?

Mr. Wilkinson: Could I detail the nature of the controversy? Well, in briefest essence, the purposes intended to be served by channelization are, as the EPA guidelines say in identifying them, flood control and drainage of wetlands. These are on agricultural lands, to either enhance or restore the productivity of farmlands and increase production of food and fiber.

Secondly, for flood protection or flood damage alleviation. Here the objective is again, essentially, economic rather than environmental, obviously. It's to protect urban areas, or to protect against frequent flooding of farmlands, again, in agricultural regions.

Finally, there is the recognition of a third major intended purpose of channeling, namely for navigation. I guess the Tombigbee Project is a good example of that.

I use the extreme example of a point of no return—the vast, interior, heartland navigation system. So I think the two objectives, economic and environmental, come head on here and the controversy received quite a bit of attention when the Council on Environmental Quality decided to have a general assessment of channelization made.

So, the nature of the controversy, the issue if you will, is economic versus environmental.

Comment: The last comment suggests perhaps that you equate integrity, for use administratively, with the idea of nondegradation to define integrity. Could you elaborate on that just a little bit?

Mr. Wilkinson: I don't understand all I know about the principle of nondegradation which has been applied to air quality, but it seems that there the trend has been to take a pre-existing ambient air quality or air quality condition and then say we can't do much about that. We can try to improve it, but let's accept that as it is, the baseline precondition, and not try to make all air pure everywhere, consistent with the principle of integrity, as we're trying to do with it here.

Or the other was non-use. There has been a lot of administrative effort to define "where do we go from here" in air quality, and this principle of nondegradation of a pre-existing situation or an air quality as it is now found has come to be accepted, I believe, as a point of departure and one might define that as some background condition, such as integrity of water and integrity of air.

Comment: Then you would suggest that the existing physical integrity would be a point of departure?

Mr. Wilkinson: That's right.

Comment: And put that into some kind of overall environmental assessment?

Mr. Wilkinson: This is not to deny improvements in it, but it's in lieu of that impossible goal of going back to integrity as it's defined, say as correspondence with an original condition.

Comment: Are you putting any significance on the words "where attainable" in the Act? Especially when it says that in the Mississippi system this might not be attainable?

Mr. Wilkinson: Right. It's a point of no return. It could be, it's not an irreversible or irretrievable situation.

The people who write Environmental Impact Statements, when they come to that section, and I've written some myself, the irretrievable or irreversible; well, you can take a dam out, you can take a whole series of dams out. It's physically possible, but hardly a realistic option.

Comment: I'd like to make a couple of comments.

First of all, I don't think your response is very good in reply to the question about what the controversy with the Council on Environmental Quality was all about.

In the first place, you implied that it was economic versus environment. That is only part of it. The major charges that have been leveled against all of the channelization projects that have been done was that they are using tax dollars to benefit a handful of land owners, to help them improve their own property at the cost of a natural resource.

And, that certain channelization projects, in fact, benefited major industries. So there is a lot more than simply facing environment versus economics. Some of the channelization projects were actually counter-productive in terms of controlling floods.

Then I would just like to raise a question; you implied that channelization of our natural systems somehow could have benefits that, well, though it might hurt some organisms, it might open up a channel so migratory fish could come up. I think that the scientific evidence that has been brought out in statements before the House Government Operations Committee runs sharply counter to that.

In fact, at the hearing where you testified, Dr. Vannote, who testified along with you, said, I believe with reference to our natural stream system, the evidence is so conclusive that channelization has just about totally grounded out the productive capacity of the stream.

And yet, you imply in your remarks today that it might help out, it might turn the stream into a biological desert. And I suggest that one example of how bad the effects could be can be seen just by going south about 65 miles to Gilbert's Run in Maryland and looking at what happened to a fine stream that hosted migratory fish. It has now been totally wiped out to benefit a couple of land owners.

I just offer these remarks contrary to some of the things that you said. The issue of channelization is not over messing around with drainage ditches on streams that don't flow. It has been with the destruction of various productive natural systems, hardwood swamp areas which are rich in fish and wildlife resources.

Mr. Wilkinson: Evidence remains at issue. Those are very good points. I'm sure that I could take you to channelization jobs that exemplify the extreme range of effects, and those that didn't benefit just a handful of land owners, but a railroad that didn't even get into the benefit cost calculations.

I don't dispute that at all. I don't think it's quite fair of you to cite Robin Vannote's comment in the testimony. At this lecture that I cited at the opening of my remarks, Robin was there too, and we had a little chat about our testimony and that of Ruth Patrick. We both realized what had to be brought out at that time under the circumstances, to reflect the diversity of our findings in this field.

Chairman Ballentine: I have one question. Mr. Blackwell, would you categorize all channelization projects as bad? I wasn't clear on your comment. There are bad aspects to almost any project. What kind of balancing test do you propose?

Comment: I just say that we are not worried about a lot of channelization projects if there is not a resource present that would be destroyed. The reason that channelization became an issue is the fact that these projects were being carried out with tax dollars to destroy important natural values.

And for people to say that you say that channelization is wrong, per se; well, how are you supposed to answer a question like that? We wouldn't have any complaints if there were not significant environmental losses occurring. It's because of those losses that we call for major reforms in policies.

And yet, the Soil Conservation Service, if you read the Environmental Impact Statement, is going right ahead with about 1,500 miles of channelization listed in the past 2 years in their Environmental Impact Statement filed with the Council on Environmental Quality.

I don't think the Agency has taken to heart the criticisms that have been brought.

Chairman Ballentine: Would you mind identifying that report to the reporter?

Comment: The Hearings of the House Government Operations Committee. There are six volumes of Hearings; it's the Subcommittee on Conservation and Natural Resources. In those Hearings there are extensive bibliographies of related works.

Comment: I would like to ask Mr. Wilkinson if in his investigation he got involved with the effects of the locks and dams on the Ohio and Upper Mississippi and other impoundments which, in effect, created almost waste stabilization ponds in rivers which, I believe, may have a very great effect on digesting the pollutants of the stream and improving water quality, plus or minus oxygen problems below such structures? Did you find that there was an improvement in the dissipation of organic materials in the reservoirs and the deep channels?

Mr. Wilkinson: To answer the first part of your question: we did not get into navigation projects because, at that time, the interest in exploring the problem was not navigation projects, it was in the small projects in relatively minor tributary areas. And it was largely because of that, the definition of the projects, that our statistical analysis found that about 50 percent were of a drainage rehabilitation kind. We did not get into major rivers, major navigable streams. But you've got a good point there.

Comment: The reason I asked the question, in part, is that the management of pollutants in storm water runoff is becoming a greater and greater problem to the Nation and especially to urban areas. And, the onsite retention techniques don't really get too effective on pollution.

So I think there seems to be a lack of information on the effect of small detention reservoirs or impoundments in improving the quality of storm runoff in various places and various situations.

And I just wondered if anybody has any light he could shed on the effects of these small retention structures on improving water quality?

Mr. Wilkinson: I think the subject of impoundments was on the original program, wasn't it? It disappeared.

Only one other response, it seems to me, is that the effects instream or in the impoundment ought to be studied. I think they have been, but they're quite unpredictable in terms of temperatures, stratification, and other things.

One thing that occurs to me is that you do not have the turbulence that you have in a natural flowing stream and therefore, the reoxygenation capacity, but that's getting a little bit beyond my field.

BIOLOGICAL INTEGRITY— A QUALITATIVE APPRAISAL

BIOLOGICAL INTEGRITY OF WATER— AN HISTORICAL APPROACH

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To a considerable extent the topics assigned to us have unreasonably artificial boundaries, because an ecologist cannot talk about the physics, chemistry, or biology of water separately, nor about the qualitative aspects of water and its biotas separately from the quantitative aspects. Moreover, in a meeting such as this of persons with disparate backgrounds and interests, effective communication can be a problem. We all tend to use words that have special meanings within our own disciplines and we assume a certain understanding of premises, principles, and laws when we use them. To make certain that we all are operating on the same wave length I shall present several principles of ecology that must guide our thinking about water, its management, and the potential effects on it of various manipulative processes, then give my own definition of the integrity of water, and finally address the topic assigned me. The principles to be discussed apply to all aquatic systems, but the examples I shall present will be concerned chiefly with lakes, as they, along with the oceans, provide in their sediments the only record of past events not covered by written observations or the memory of persons still living.

(1) Lakes and rivers are integral parts of larger systems—the watersheds or catchment areas that are drained by the rivers or drain through the lakes. Besides water itself, the catchment area contributes dissolved and particulate substances, both mineral and organic. In addition, usually lesser quantities of various substances are contributed directly to the water from the atmosphere by precipitation and dry fallout. Together with such process-regulating variables as light, temperature, current velocity, et cetera, these various substances comprise the abiotic portion of the aquatic environment and help control the diversity and abundance of aquatic organisms.

(2) Those substances that are used directly by aquatic organisms and are necessary in their metabolism—usually called essential nutrients—are recycled in the system by biological mechanisms. Storage in living biomass, in wood or sediments, or in the deep water of a stratified lake can delay the reutilization of these nutrients for varying periods of time. Because inputs and outputs, including storage, are generally in balance, an aquatic system to remain functional requires a continuous input of nutrients. The quantities of nutrients and other substances contributed by a watershed vary with the geological nature of the substrate and its overlying soils, the vegetational cover of the land, and climate. Since all of these tend to form regional patterns, it is not surprising that rivers and lakes also tend to form regional patterns or clusters in their chemistry, productivity, and biotic diversity.

(3) Besides nutrients there must also be a source of fixed energy, mostly in organic compounds. The latter derive both from photosynthesis accomplished within the aquatic part of the system and from organic materials, such as leaves, pollen, and leachates produced in the terrestrial part of the system. In some systems, such as lakes with small, nonforested watersheds, virtually 100 percent of the available energy derives from autochthonous photosynthesis, whereas in other systems, such as small, headwater streams in heavily forested regions, almost all the fixed energy derives from organic detritus of terrestrial origin. But whatever its origin, the fixed energy in organic substances is the driving force that enables the organisms present to metabolize and carry on their life processes. As the energy is used in metabolism it is transformed into heat and dissipated from the system. Hence, unlike nutrients, energy cannot be recycled. It is a one-way street, but like nutrients there must be a continuous supply for the ecosystem to function.

(4) Taking into consideration regional differences in water chemistry and nutrient supply and differences between water bodies in energy availability and efficiency of nutrient recycling, each aquatic system has accumulated over time a diversified biota consisting of many species of organisms ad-

justed to the particular set of conditions in the water body in question. For purposes of analysis and construction of models, these organisms are often clustered into such functional groups as primary producers, herbivores, detritivores, carnivores, decomposers, et cetera, but all are interrelated. That particular species occur in a given lake or river is partly a matter of the species pool of the region and the dispersal capabilities of the individual species, partly a function of the biotic and abiotic relationships in the water body. Although we consider these systems to be in a steady state, intuitively we expect the biota to adjust to long term changes in climate, vegetation, soil development, and internal trends within the system itself, and we also expect the system to be able to accommodate ~~and~~ eventually recover from such short term natural stresses as scouring flushouts in rivers, episodes of volcanism, landslides, and so forth. Homeostasis is restored.

This, to me, is what is meant by the integrity of water—the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region. Such a community can accommodate the repetitive stresses of the changing seasons. It can accept normal variations in input of nutrients and other materials without disruptive consequences. It displays a resistance to change and at the same time a capacity to recover from even quite major disruptions.

My assignment is to consider what history tells us about the response of aquatic systems. Anything that happened in the past is history. Even the words I speak become a part of history as soon as they are spoken. But most of history is unrecorded and hence unavailable for interpretation. In the case of aquatic systems there are anecdotal accounts of particular events or conditions that may have some comparative value. There may be time series of accumulated data for particular rivers or lakes that document what happened during these intervals. And, in the case of lakes (and oceans), the accumulated sediments constitute an historical record of changing climate and watershed conditions and the integrated response of the lake to these changes. Where no previous studies on particular lakes exist and likewise no isolated anecdotes about particular events, the only means we have of interpreting previous conditions is from the sediments. For rivers this possibility does not exist at all, as there is no long term sequential accumulation of sediments. Hence, here we are completely dependent on the written record, except for the geomorphic and hydrologic changes that can be interpreted from the landscape and residual sediments of the valley.

I do not intend to say much about rivers. Their response to point source additions of domestic and industrial wastes is the establishment of a longitudinal gradient involving a succession of chemical processes and organisms, which for organic wastes is sufficiently predictive that a series of zones—the sabrobic system—has been set up to help describe and interpret the process of recovery. Other zone designations have been devised for various kinds of industrial wastes and the responses they elicit.

Organisms vary greatly in their sensitivity to environmental changes accompanying pollution. Fishes together with a majority of insects and molluscs are most sensitive. Blue-green algae and a few miscellaneous animals from several groups are most resistant. These differences in tolerance lead to a greatly simplified community at the point of maximum impact, with the organisms tolerating the conditions here often occurring in tremendous numbers, and then to a gradual buildup in diversity of species and equitability in numbers of individuals downstream. Various diversity indices have been proposed to help quantify these changes. Diatoms are particularly useful in stream studies and their truncated log-normal distributions are useful in assessing the severity of pollution. The experienced investigator can often determine quite easily from the macroinvertebrates present what the stage of recovery is, and can also detect residual effects of pollution, as from lead mines in Wales, that are no longer detectable chemically.

Lakes are fundamentally different from rivers in a number of respects that affect the integrity of water as I have defined it. In the first place, their water movements are not gravity-controlled, unidirectional flows which continually flush out the channel with new water from above, but rather wind-induced circulations. Typically in summer, when the wind is not adequate to overcome the differences in density set up by surface warming, the lake becomes divided into an upper circulating epilimnion and a lower zone, the hypolimnion, cut off from the surface by a steep density gradient and as a result subject to generally much weaker water movements than the epilimnion. During periods of calm weather those lakes that circulate continuously over summer can become temporarily stratified and even the epilimnion of the others can develop secondary stratifications under these circumstances. Regardless of the duration of such stratification, the hypolimnion, or its equivalent in temporary stratification, experiences cumulative chemical changes, most important of which is the gradual depletion of dissolved oxygen by biological activity. The longer the duration of stratification and the greater the amount of biological activity, the more severe will be the oxygen depletion with its attendant stresses on organisms requiring certain levels of dissolved oxygen for their survival.

Unlike rivers, lakes accumulate sediments progressively and sequentially. One effect of these sediments is gradually to reduce the volume of the hypolimnion over time and hence the total volume of dissolved oxygen it contains when stratification becomes established in spring or summer. Consequently, even without any increase in biological activity, the hypolimnion will experience a gradual reduction in oxygen concentration over time, which brings about the extinction and replacement of various deepwater organisms as their tolerances for low oxygen are exceeded.

The sediments constitute a storage for energy and nutrients. Some of this is utilized by bacteria which can continue their activity even to considerable depths in the sediments, or by various animals, which because of their need for molecular oxygen are confined generally to the uppermost few centimeters. Whether the sediments are functioning chiefly as a sink or as a reservoir for nutrients is important in problems concerning eutrophication and its management.

The sediments also constitute a chronological record of processes in the lake and conditions in its watershed, including climate. A perceptive reading of the record—its chemistry, physics, and paleontology—gives us much insight into the stability of lake systems when subjected to various stresses, including those resulting from man's activities, and their rates of recovery.

A third major difference between rivers and lakes is that the water in lakes has a certain residence time, up to 100 years or more in some of the large lakes, determined by the relationship between the input of water from the catchment area and direct precipitation and the total volume of the lake. This allows for the recycling of nutrients in the same place, subject to the constraints imposed by stratification, and the buildup of a diverse community of small floating organisms—the plankton. And even apart from any storage function of the sediments, the residence or replacement time means that there is an inherent lag in response of the system to any increase or decrease in inputs of nutrients or other substances having biological effects. In streams the response to input changes can be almost immediate. Any storages in the sediments are mostly temporary, as the sediments can be swept downstream during the next flood stage.

What I should like to do now is present a few examples of the kinds of responses made by lakes to various stresses.

It was almost axiomatic in limnology until quite recently that lakes increase in productivity over time through natural causes, a process that has been termed natural eutrophication. This idea seemed to be substantiated by some early studies in paleolimnology which showed that the organic content of the sediments increased exponentially over time from a very low level initially to a certain plateau level—the trophic equilibrium—which was then maintained essentially unchanged almost to the present. The trophic equilibrium was regarded as a state in which production was no longer limited by nutrient supply but rather by such factors as light penetration that affect the efficiency of utilization and recycling of nutrients within the system.

The sedimentary chlorophyll degradation products (SCDP) in sediments originate almost entirely from photosynthetic plants, chiefly algae, in the lake itself. Present evidence suggests that these organic compounds are relatively stable in sediments. Hence, the quantitative changes over time of these substances can give an indication of the magnitude and changes in productivity experienced by a lake. One core from Pretty Lake, Ind., (Figure 1), shows low SCDP and hence low productivity in late glacial time and then an exponential increase to a maximum, maintained essentially at plateau level almost to the present. This corresponds to the classical interpretation of the trophic equilibrium in lake ontogeny. But the second core from shallower water shows a decline in SCDP after the maximum following the exponential increase, which does not fit the model.

We now know from this and other studies in paleolimnology that change in productivity over time is not unidirectional from low to high in all lakes, but that some lakes had a period of high productivity initially and then became less productive subsequently. Others had discrete episodes of higher productivity from whatever cause. For example, Lake Trummen in southern Sweden (Digerfeldt, 1972) had high accumulation rates of organic matter, nitrogen, and phosphorus at the beginning of postglacial time approximately 10,000 years ago. These subsequently declined and remained low up to very recent time, when industrial organic effluents completely changed the character of the lake (Figure 2). These relationships are interpreted as reflecting the high early availability of nutrients from the youthful soils of the regional till sheets, with the subsequent decline resulting from the progressive impoverishment of the soil by leaching and by the reduction of subsurface inflow into the lake as basin-sealing sediments accumulated.

Hence, the productive status of a lake is depend-

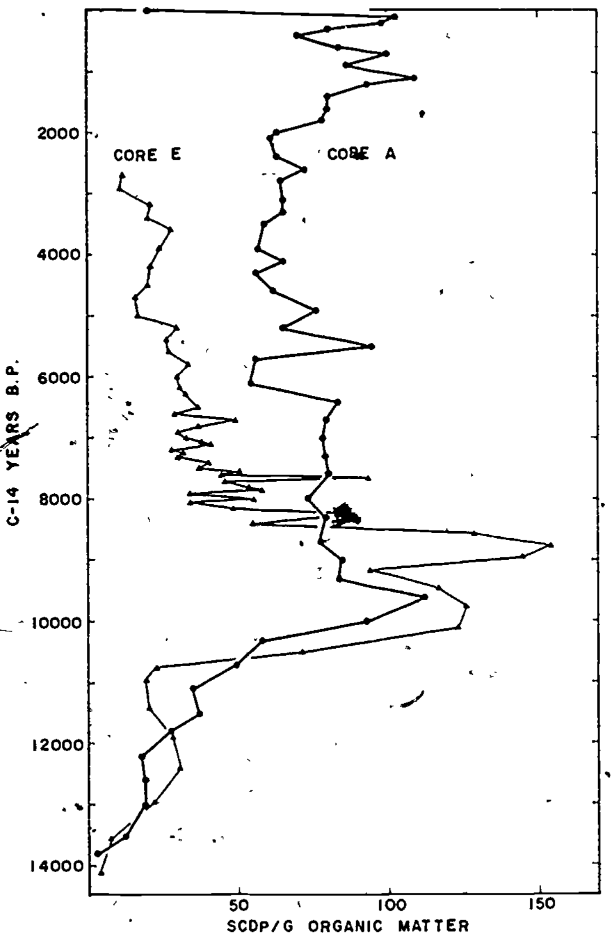


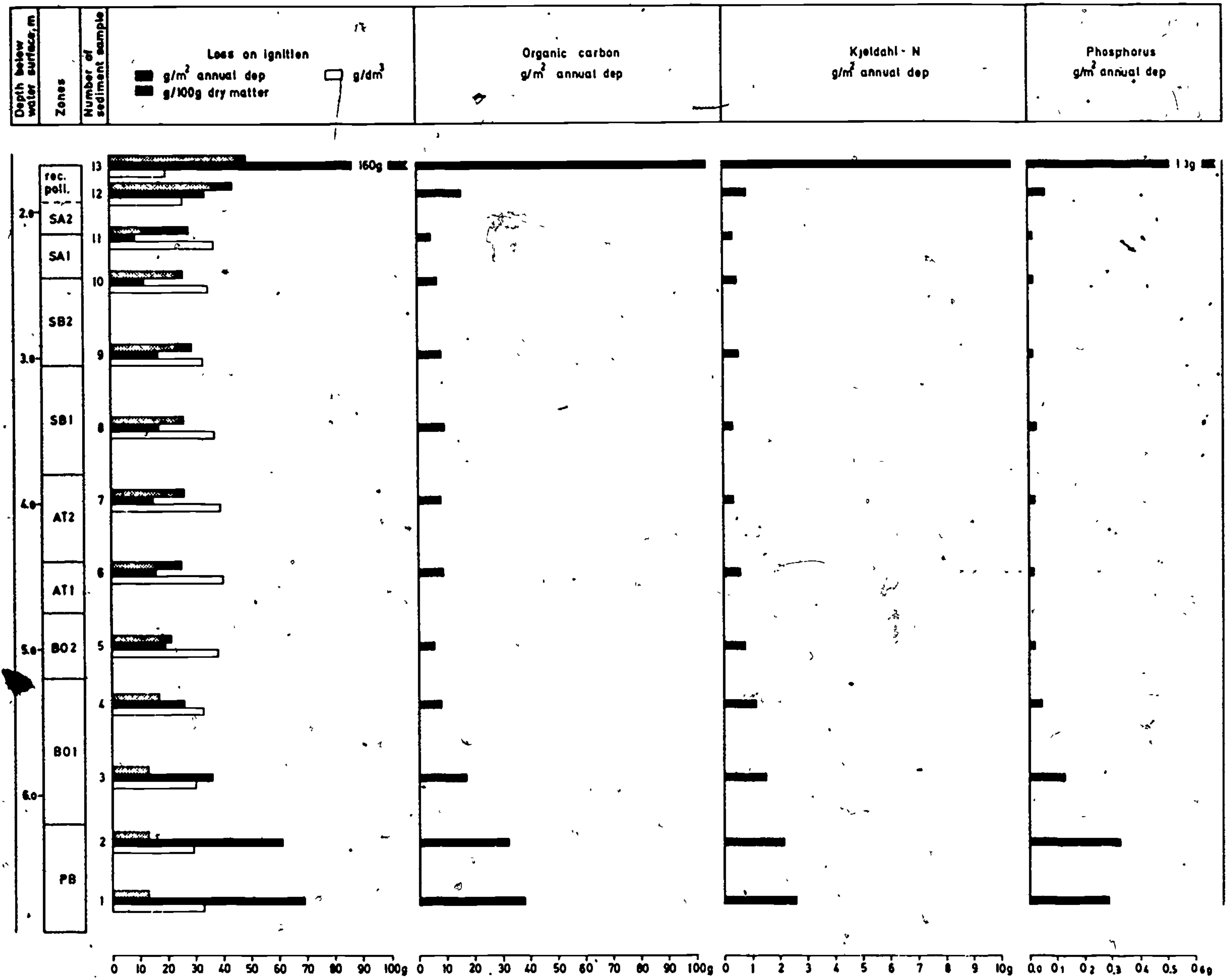
FIGURE 1

ent on the magnitude of its nutrient inputs, subject to the internal controls of the system. If we can decrease the nutrient supply, we can expect a more or less commensurate decrease in productivity. Various attempts are being made to model the magnitude of the response expected from any reduction in nutrient loading, but the rate of response is still unpredictable. The rapid reduction of phosphorus and productivity in Lake Washington following the elimination of secondary sewage effluents (Edmondson, 1972) is encouraging, although some other components of the system, such as nitrogen, did not behave in the same dramatic way. Other examples to be presented suggest that the response time of the total system, or perhaps better the rebound time from a stressed condition, can be much longer than in Lake Washington.

The responses of a lake to the decreasing oxygen concentration of the hypolimnion over time are instructive and significant. Western Lake Erie is so shallow that it stratifies only temporarily in summer during calm weather. Already by 1953 the oxygen demand of the sediments had become such that during a brief period of temporary stratification in late summer the oxygen content of the water overlying the bottom was sufficiently reduced to cause the wholesale death of the nymphs of the burrowing mayfly, one of the most abundant organisms here and a very important fish food (Britt, 1955). The mayflies never reestablished their populations but they have been replaced by smaller oligochaete worms capable of enduring quite low concentrations of dissolved oxygen. Thus, a single event, although obviously with antecedent conditions, led to a complete change in one portion of the biotic community.

The cisco is another case in point, although perhaps less spectacular. If we want to talk about endangered species, or at least endangered populations, this is one. It is a fish that lives in deep water with requirements for both low temperature and high oxygen. If either of these limits is exceeded, the fish perishes. As the summer oxygen concentration of the hypolimnion gradually decreases over time, the cisco, in order to meet its oxygen needs, is forced upward into strata with progressively higher temperatures. Eventually the combination of low oxygen in deep water and high temperatures toward the surface eliminates the habitat suitable for the cisco and the population is extinguished. In 1952 Indiana had 41 lakes with known cisco populations (Frey, 1955a). It is certain that a number of these populations have been completely extirpated since then, and it is not at all certain how long the others will survive.

The species of midge larvae associated with deep-water sediments have different requirements for dissolved oxygen, so that as the oxygen content of the hypolimnion gradually declines over time, the composition of the midge community likewise changes progressively in favor of species capable of tolerating lower oxygen concentrations. This led early in limnology to the establishment of a series of lake types based on the dominant species of offshore midges and presumably representing stages in a successional series. Fortunately the head capsules of the midge larvae, which are well preserved in lake sediments, suffice to identify the organisms to the generic and sometimes to the species levels. In general, the pattern of succession in an individual lake corresponds to the model, with species requiring high levels of oxygen occurring early in the history of the lake; these subsequently are replaced by species more tolerant of reduced oxygen; they in turn are replaced by species still more tolerant, and so on until the only species left is a mosquito-like larva *Chaoborus,* which can endure


Depth below water surface, m
Zones
Number of sediment sample
Loss on ignition
g/m² annual dep
g/100g dry matter
g/dm³
Organic carbon g/m² annual dep
Kjeldahl - N g/m² annual dep
Phosphorus g/m² annual dep
rec. poll.
SA2
SA1
SB2
SB1
AT2
AT1
BO2
BO1
PB
2.0
3.0
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0 10 20 30 40 50 60 70 80 90 100g
0 10 20 30 40 50 60 70 80 90 100g
0 1 2 3 4 5 6 7 8 9 10g
0.0 0.1 0.2 0.3 0.4 0.5 0.6g

FIGURE 2

anaerobiosis for a while, but eventually even it is eliminated if conditions continue to deteriorate.

The most incisive study to date is that of Hofmann (1971) on Schöhsee in northern Germany. A midge community associated with moderate oligotrophy dominated the offshore community until early sub-Boreal time about 1500 B.C. This was followed by a transitional community lasting perhaps 2,500 years, and this in turn by a eutrophic community for the last 1,000 years. The whole story is much more complex than indicated by this too-brief summary in that throughout the 10,000 years of lake history there were migrations of originally shallow-water species into deep water, extinction of deepwater species, and successional dominance of one species or another as conditions gradually changed. Actual quantitative studies of the benthos in 1964-67 compared with similar studies in 1924 show that the populations are still changing (Figure 3). In this interval the population of chironomids, especially *Chironomus,* has declined drastically, being replaced by an increasing population of oligochaetes. *Chaoborus* remained about the same. This situation is reminiscent of western Lake Erie, where oligochaetes took over after the big killoff of mayflies in 1953.

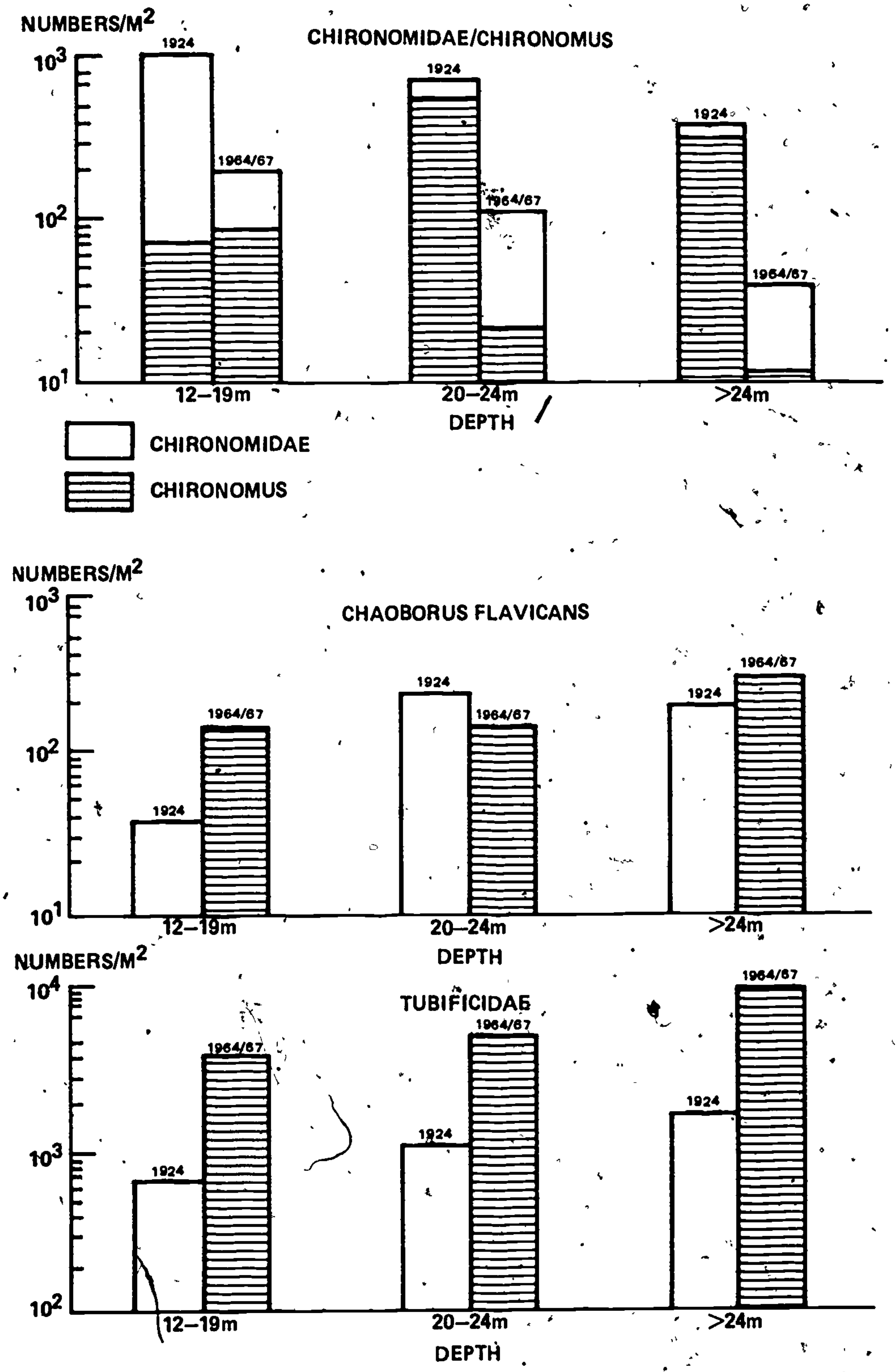
Settlers first moved into the Bay of Quinte region of Lake Ontario about 1784. Government reports describe the devastation of thousands of acres by lumbering and the erosion problems resulting. The initial impact of this land disturbance on the Bay was to change the deepwater sediment from silt dominance to clay dominance and to bring about a marked decrease in organic content through dilution by clay (Warwick, 1975). Subsequently, the organic content increased gradually, although it is still less than pre-impact level, but now there is a pronounced decline in oxygen content of the deep water in summer. The initial response of the midge community was somewhat surprising; it became more oligotrophic than it had been before but then it proceeded through several successional phases to a quite strongly eutrophic stage at present (Figure 4). Unlike previous investigators, Warwick believes that the earliest stages in midge succession are controlled by food supply more than by the minimum annual concentration of oxygen in the hypolimnion. The latter is important chiefly in the later stages of succession. Besides the shift in lithology from silt to clay, the sediments deriving from the impact period are marked by the appearance of the pollen of *Ambrosia* (ragweed), the abundance of which in the sediments roughly parallels but lags somewhat behind the curve showing increase in population of the region. *Ambrosia* provides an excellent time-stratigraphic marker in eastern North America for forest clearance and the initiation of agriculture.

Man's effect on our water resources is nothing recent. Figure 5 is a pollen diagram of Längsee in southern Austria (Frey, 1955b), a lake that presently has a layer of water at the bottom that does not participate in the circulation of the rest of the lake in spring and autumn—a condition known as partial circulation or meromixis. At a particular level in the sediments, which is obvious in the diagram, there are sudden changes in the non-tree pollens, including the appearance of various agricultural weeds and occasional grains of such cultivated plants as cereals and walnut, as well as a disruption in the development of the forest vegetation. At this same level discrete bands of clay occur, separated by a black reduced sediment completely unlike the stable sediment deposited prior to this but identical to what occurs above. Quite obviously, this is when agriculture began in the region about 2,300 years ago, and just as obviously the clearance of the land for agriculture resulted in the inwash of large quantities of clay into the lake, triggering the condition of partial circulation, now maintained by biological means. Hence, the sudden import of large amounts of clay into a lake can have different consequences for different systems.

Lago de Monterosi, a small volcanic lake in central Italy about 40 km from Rome, had an initial small burst of productivity when formed about 25,000 years ago, then a long phase of low productivity up to Roman time, when the construction of a road, the Via Cassia, in 171 B.C. completely changed the input of nutrients and other substances from its small watershed (Hutchinson, et al. 1970). The lake responded by dramatic increases in productivity and sedimentation rates which did not peak until almost 1,000 years after the disturbance (Figure 6). Since then, productivity, as inferred from the accumulation rates of such substances as organic matter, nitrogen, et cetera, has subsided to a level not much greater than that existing before the disturbance. The lag in response and the long duration of the response are probably related to the fact that Monterosi is a closed basin with no permanent streams draining its very small watershed and with output only via seepage.

Grosser Plöner See is a lake in northern Germany famous for the many studies in limnology conducted there by August Thienemann and his associates. In 1256 A.D. a dam constructed at the outlet, raised the water level about 2 meters, overflooding much flatland in the process and greatly increasing the extent of the littoral zone. The response of the lake was spectacular (Ohle, 1972). The sedimentation rate, which had increased slowly from about 0.1

SCHÖHSEE BENTHOS 1924 AND 1964/67



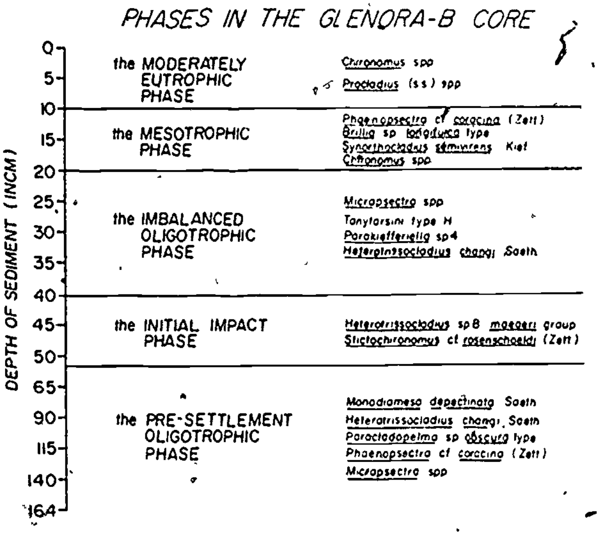


FIGURE 4

mm per year at the beginning of postglacial time to only about 0.5 mm per year 9,000 years later, suddenly jumped 20-fold to more than 10 mm per year. This has resulted in half the 15 meters of sediment in the lake deriving from only the last 700 years of the lake's existence. The big increases at this time in the accumulation rates of such substances as zinc, copper, cobalt, and aluminum reflect the increased input of mineral substances to deep water from the overflooded land and probably from the watershed also. Correspondingly big increases in the accumulation rates of organic matter, chlorophyll derivatives, and diatom silica reflect the big increase in production within the system resulting from this changed regime (Figure 7).

The lake level had been raised to power a mill dam, as was common in northern Germany at this time, and also to facilitate the production of eels, but the concomitant flooding of valuable agricultural lands resulted in a long-continuing strife be-

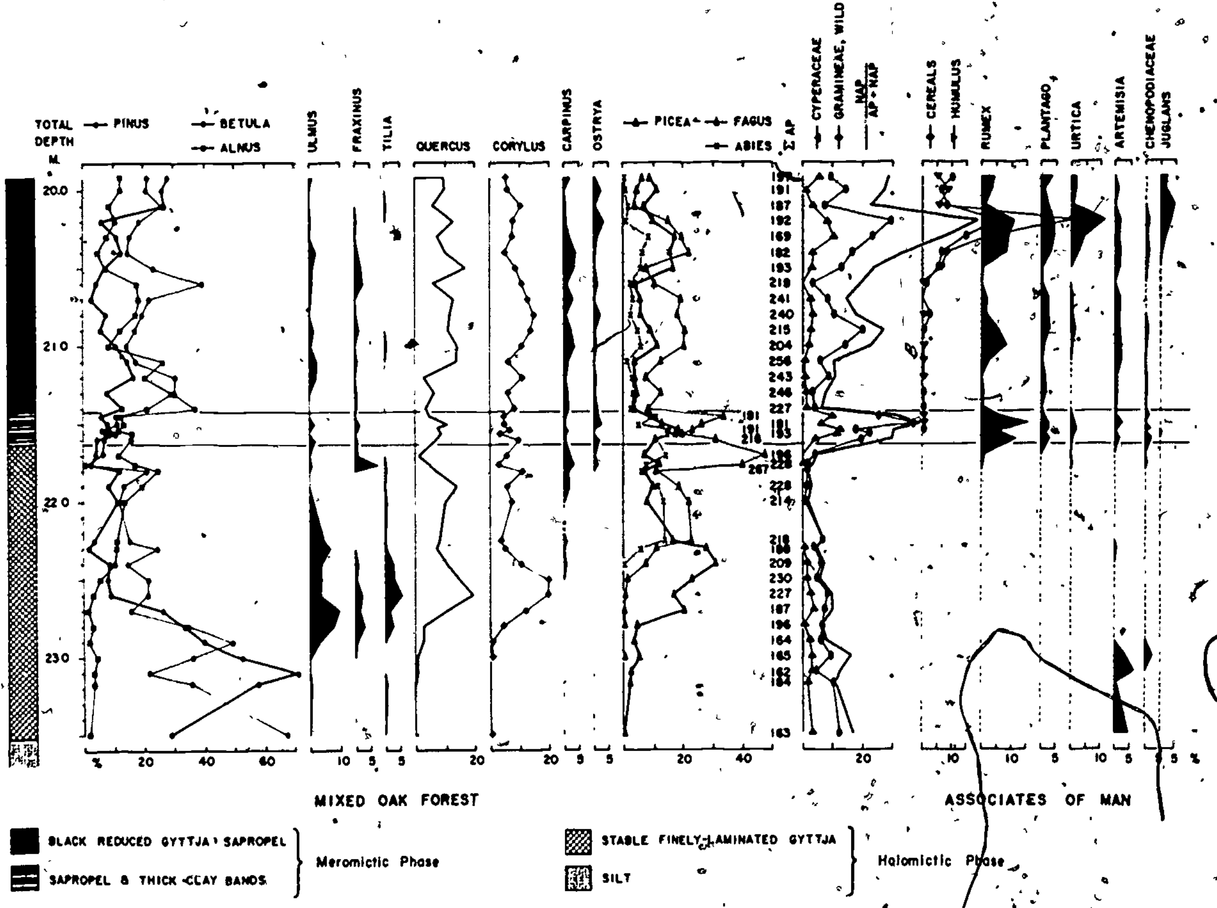


FIGURE 5

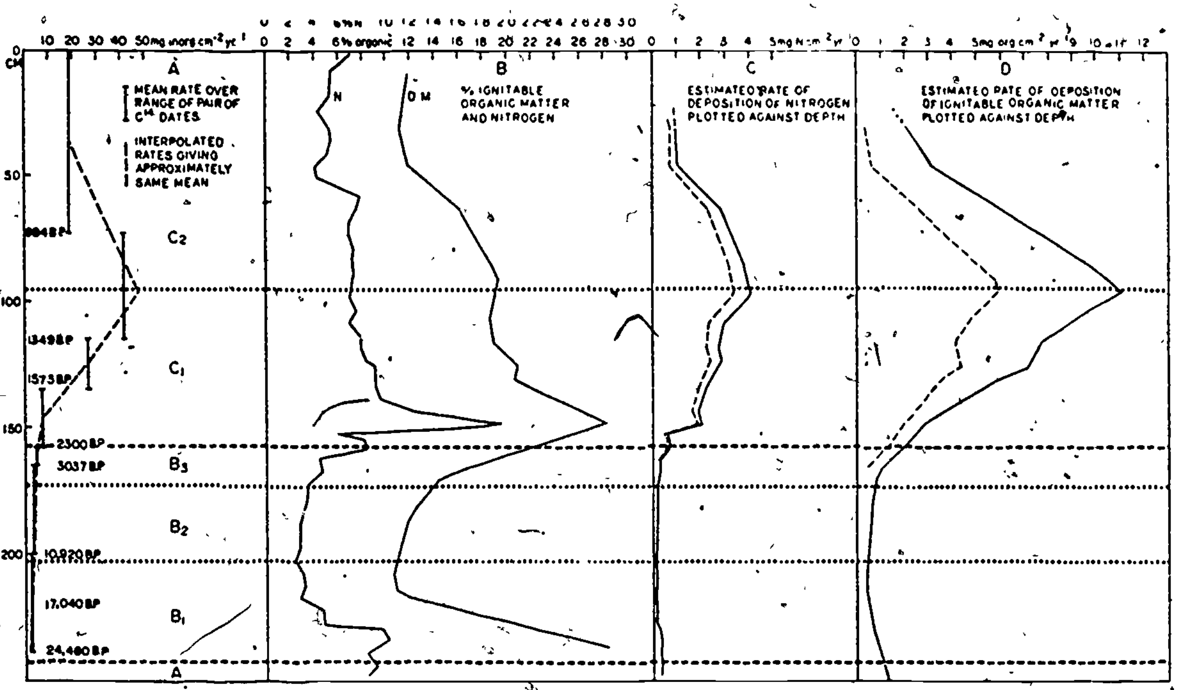
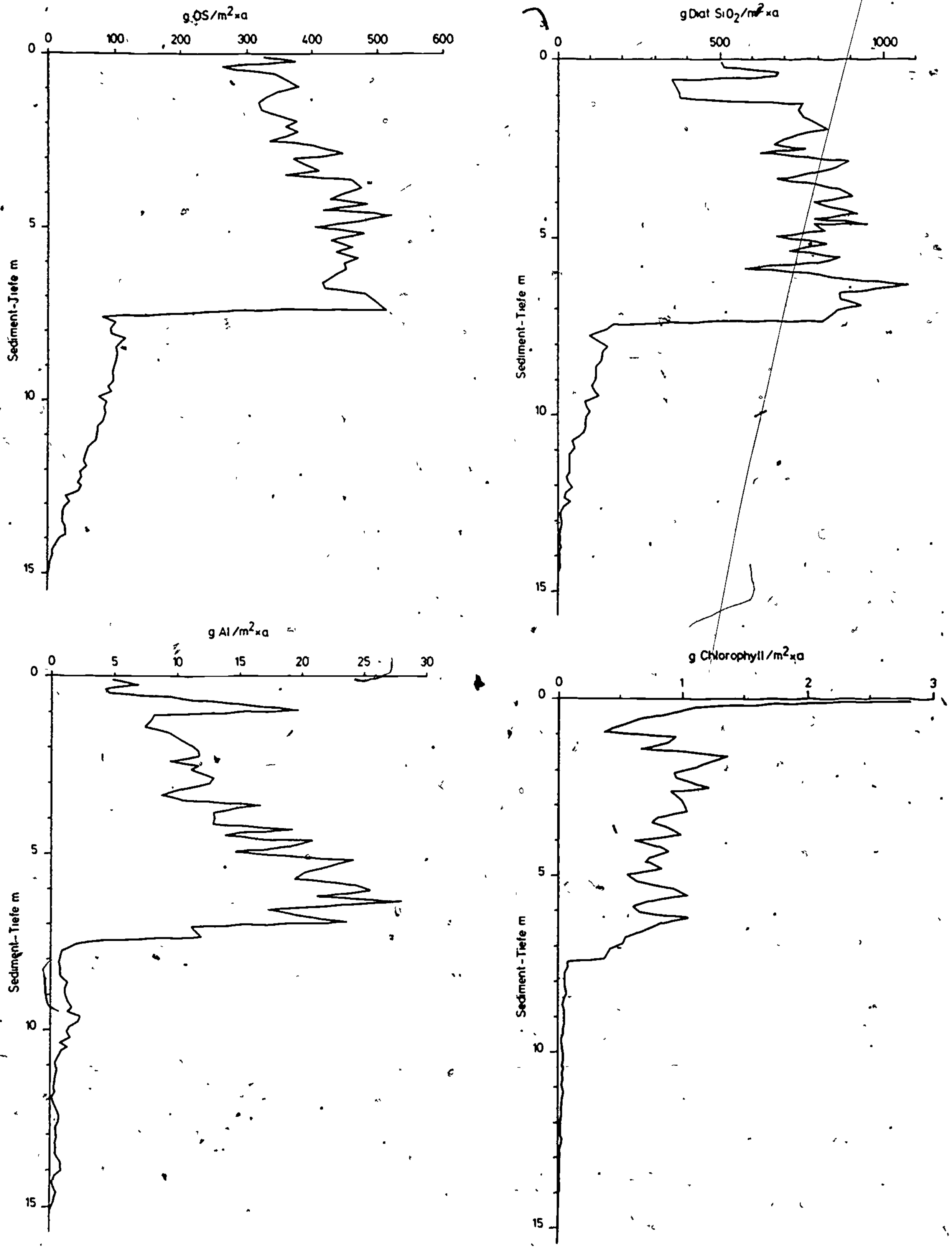


FIGURE 6

tween the mill operators and fishermen on the one hand and the manor owners and farmers on the other. Finally, in 1882 the lake level was lowered by 1.14 m. Up to this time the accumulation rates of most mineral substances had been declining irregularly, and likewise the indicators of biological activity. The sudden lowering in lake level resulted in the erosion and deposition offshore of sediments that had accumulated in shallow water, yielding a discrete horizon of coarse-grained sediments and associated sharp peaks of various mineral constituents. Accumulation rates of chlorophyll derivatives and diatom silica declined at this time, perhaps through light limitation of production by increased inorganic turbidity. The large increase in chlorophyll derivatives in very recent time, reflecting high productivity, is attributed to the heavy use of agricultural fertilizers and phosphate detergents and to the draining of the surrounding wetlands. Such an increase of organic matter and other indicators of production toward the surface is commonplace among lakes being stressed by man, frequently resulting in a completely different type of sediment than anything deposited earlier.

Grosser Plöner See is but one of a number of instances where the productivity of a lake has been markedly increased by raising its water level. The present high productivity of Grosser Plöner See is shared by many lakes of the region, all accomplished within the past few decades in direct response to man's increasing impact on the systems. Ohle (1973) has used the term "rasante Eutrophierung" (racing eutrophication) for this rapid response of lakes to cultural influences, in contrast to the generally slow, balanced development occurring naturally.

The most abundant animal remains in lake sediments are the exoskeletal fragments of the Cladocera, particularly the family Chydoridae (Frey, 1964). They are abundant enough for the construction of close-interval stratigraphies similar to those of pollen and diatoms and for the calculation of various diversity indices and distribution functions. Since the deepwater sediments represent an integration over time and habitat, the population of remains recovered from the sediments is partly artificial, in that all the species represented probably did not co-occur at the same time and place. Yet the diversity indices of the chydorids do show certain demonstrable relationships to such variables as productivity and transparency and, as shown in Figure 8, the relative abundance of the various species in an unstressed situation conforms almost precisely to the MacArthur broken stick model for contiguous but non-overlapping niches (Goulden, 1969a). Hence, the species distribution predicted by this model can be used to assess the extent of imbalance in the system.


g OS/m²×a
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100
200
300
400
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g Al/m²×a
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FIGURE 7

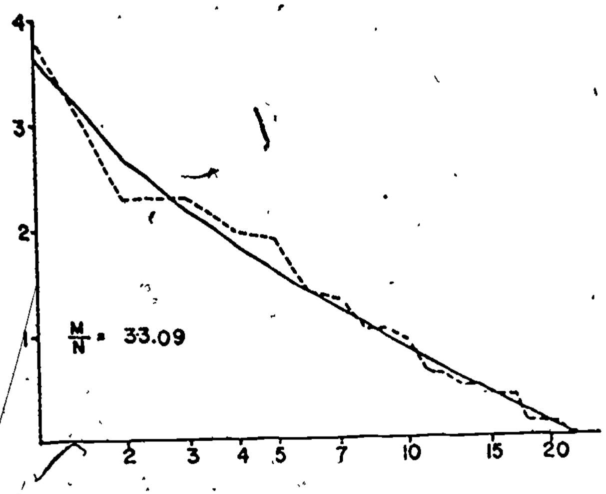

FIGURE 8

In a series of 21 lakes in Denmark for which measurements of annual phytoplankton photosynthesis by radiocarbon uptake are available (Whiteside, 1969), there is a direct relationship between species diversity and transparency and an indirect relationship between species diversity and productivity. There is also an inverse relationship between transparency and productivity. The interpretation of these relationships is that as lakes become more productive, they become less transparent from the development of larger phytoplankton populations, and with higher productivity the chydorid community is thrown out of balance, quite possibly from a reduction of habitat diversity through the curtailment of species diversity and areal extent of the aquatic plants which form the major habitat of the chydorids. And since the chydorids are but one component of a complex community, one can assume that the community as a whole has been stressed by an increase in productivity.

In another study in Denmark, Whiteside (1970) attempted to establish the predictive value of chydorid communities for lake type, and then attempted to use these results in interpreting changes in lake type in postglacial time in response to climate and vegetational patterns of the watersheds. A hard water, eutrophic lake (Esrom Sø) was sufficiently buffered internally that it went placidly about its business during postglacial time almost regardless of external stresses that would be expected to have repercussions on the system, whereas a soft water, oligotrophic lake (Grane Langsø) reacted nervously to even small external stresses. Thus, the response to a given stress can be expected to vary greatly from lake to lake depending on its particular suite of ecological conditions and balances.

The MacArthur predictive model has been used to assess community stresses resulting from the rapid climatic change of the last interstadial (Goulden, 1969a), from episodes of Mayan agriculture in Central America (Goulden, 1966), and from volcanic ash falls in a lake in Japan (Tsukada, 1967). The last study (Figure 9) is interesting in showing that a single instantaneous but massive perturbation, as from an ashfall, can have marked and long-lasting effects on the community structure of a lake.

There are quite a few other studies on the responses of lakes to stresses that might be cited, but I should like to give just one more. The paleolimnology of North Pond in northwestern Massachusetts is being studied intensively by Tom Crisman, a graduate student at Indiana University. Many major changes, almost as precipitous as those in Grosser Plöner See, occurred in the lake shortly after the pine forest represented by pollen zone B was replaced by deciduous hardwoods. Productivity in the lake, as evidenced by the quantity of chlorophyll derivatives in the sediments, increased dramatically at that time, along with nitrogen and phosphorus. A species of planktonic Cladocera, *Bosmina coregoni*, which is usually considered characteristic of more oligotrophic situations, was replaced almost instantaneously by *Bosmina longirostris*, characteristic of more eutrophic situations (Figure 10). Since there is no clear evidence for any major fluctuation in water level and since it is unlikely the Amerindians could have modified the watershed to any appreciable extent, the only correlate and possible cause is the shift in forest composition. But this is difficult to reconcile with the data, because watershed studies to date have demonstrated that deciduous forests are more parsimonious than coniferous forests in releasing nutrients from the system.

Let me attempt to summarize some of the major points developed. Lakes change biologically during their existence from changing inputs of nutrients and energy and from changing internal control mechanisms, associated in part with stratification and depletion of oxygen content in deep water. The biological changes in many instances have been gradual, although in others they have been sudden, associated with natural catastrophes, major changes in water level, or even changes in the dominant vegetation type in the watershed.

Lakes vary in their sensitivity to external stress and in their rapidity and magnitude of response. Man's chief impact is to stress the systems so severely that they are thrown out of balance and the

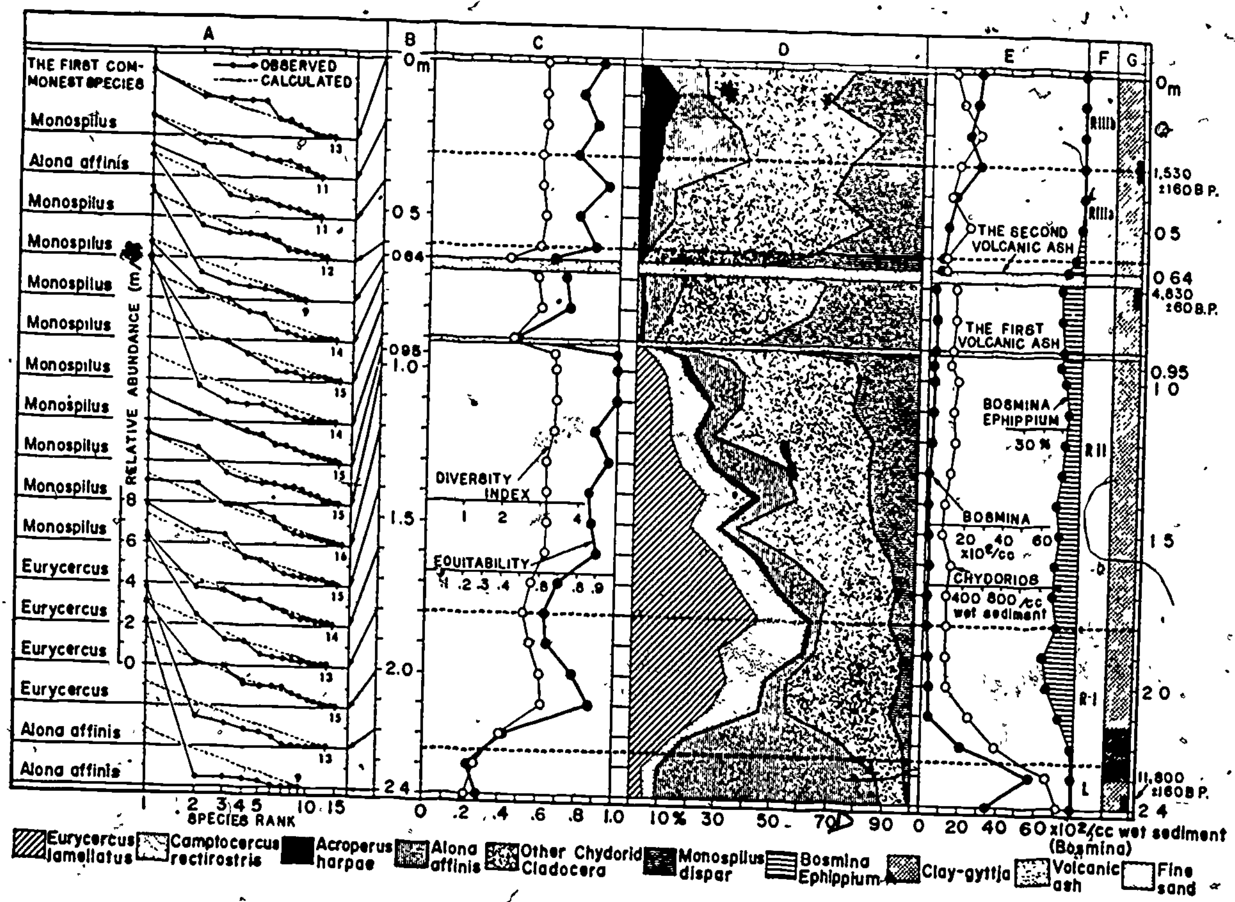

FIGURE 9

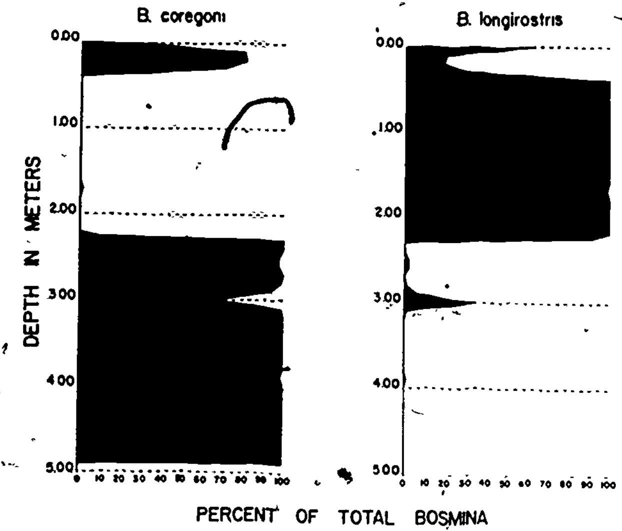

FIGURE 10

rate of change is accelerated—what Ohle calls "rasante Eutrophierung." Both for natural and man-induced stresses, the response of the total system may be fast or slow, and likewise the rate of recovery. The lag may be considerably greater than predicted from the water replacement time, amounting to hundreds of years even in small lakes if our samples from the past have been correctly interpreted. Hopefully, the response time, particularly of recovery, will be fairly short, but faced with the unpredictability of the response time, we should be much more solicitous about the stresses placed on our lakes, as even with massive engineering input they may not recover as rapidly as hoped.

Eutrophication occurs naturally, but so does the contrary process of oligotrophication. That is, a lake can become less productive with time, if its nutrient budget is decreased. Paleolimnology has not yet been able to resolve what the major controls of productivity have been in the past for any particular lake, except by inference from our knowledge of present controls. But since phosphorus, more than any other single substance, is the dominant control of productivity in temperate lakes, it is essential to keep phosphorus inputs at a minimum if we are to have any hope at all of maintaining the integrity of our lakes.

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DISCUSSION

Comment: Your definition of the integrity of water seems to be the capability of maintaining and supporting a composition of organisms that can exist in its natural state. In your discussion you described varying natural states and change of process. How does that translate to a useful definition today?

Dr. Frey: We had an example a couple of weeks ago when two young Ph.D.'s who were modeling ecosystems gave seminars at Indiana University. They had linear models which didn't allow for any change over time. However, in any particular lake there will be changes over time, induced by changes in climate and vegetation, soil development, and so forth. The response of the aquatic community to these changes will probably be adaptive adjustments in species composition and in the relative abundance of species, controlled in part by the mobility of the species. I think a definition of integrity has to include the concept of a balanced, integrated, adaptive community.

Comment: Did you go into these?

Dr. Frey: No, they are objectives.

Comment: Have you made any comparisons with other organisms over an historical period? Would you be able to use changes in the plankton population to detect changes in the water, as you pointed out is possible with fish populations? Would the changes be subtle or quite apparent?

Dr. Frey: I didn't go into any of the long term studies, because even the best of these are less than 100 years old. I know, for example, that there are records for the Chicago water supply which document the kinds and quantities of plankton in southern Lake Michigan over many decades. Probably the longest and most nearly continuous record of all is that for Lake Zürich in Switzerland. Here the deepwater sediments have been accumulating as discrete annual layers since the late 1800's. As the lake became more eutrophic under man's influence, various species of algae invaded the lake and developed to bloom proportions. These are documented by studies of the plankton. Significantly, the blooms of the various species, particularly the diatoms, are also recorded in the appropriate annual layers, so that Lake Zürich constitutes to some extent a calibration system for the interpretation of real events and changes in a lake from what is recoverable from the sediments.

Most of these long term data series have been reported elsewhere at various times. I didn't attempt to summarize them, but instead concentrated on the kinds of interpretations that can be made from the sedimentary record.

Comment: I'd like to ask you a philosophical question stemming from your definition of integrity. In your opinion, are efforts to reverse a naturally occurring trend toward eutrophication counter to the integrity of that lake?

Dr. Frey: I had to leave out a number of pages of my prepared text because of time limitations (but these are included in the published paper). For the chydorid cladocerans, which are well represented in lake sediments, the species diversity of the community declines as the productivity of the lake increases, indicating that the system is being stressed. This should not be interpreted to mean that all productive lakes are out of balance because the rate of change is probably the important consideration. Where the increased productivity is the result of man or of some essentially instantaneous event such as a volcanic ash fall, the rate of change in nutrient budgets or other environmental conditions is so great that the community cannot keep pace with orderly and adaptive adjustments. But where the forcing variables change slowly over time the aquatic biota is able to maintain an internal balance. Hence, I am in favor of either reversing the trend toward increasing productivity in our natural waters, except where this is specifically desired, or at least sufficiently reducing the rate at which eutrophication is occurring so that the system is not stressed unduly.

BIOLOGICAL INTEGRITY—1975

G. M. WOODWELL
Biology Department
Brookhaven National Laboratory
Upton, New York

Sic utere tuo ut alienum non laedas. Use your own property in such a way that you do not damage another's.

A simple precept, well established in English law, cited by William Blackstone as the basis of the law of nuisance and, I would venture, embraced by most of you and other thoughtful, reasonable men around the world. The principle has many applications. It was advanced recently by Charles Cheney Humpstone in an article in the January 1972 issue of Foreign Affairs in which he argued for an international no-release policy on pollution as the only policy that will work. The precept has its roots, of course, in the biblical morality of doing unto others as one would have them do unto him. Such a code has appealed to reasonable men for more than 2,000 years and has become incorporated into mores, manners, and our laws and interpretations of equity before the courts. As the density of people increases and the potential for intrusions on the interests of others soars, the need for strengthening the morality grows as well—or we degenerate into barbarism—and environment slides rapidly toward a chaos of progressive toxification and impoverishment.

But where lies reason today? The arguments run that reason in the management of environment lies in compromise—between the venal interests of would-be polluters and the so-called "unreasonable" idealism of that class of citizens commonly identified as "environmentalists." And so we find the Administration acquiescing in pressures to delay or annul provisions of the Clean Air Act and we watch continued pressures to weaken the Water Pollution Control Act Amendments of 1972, pressures to dissect and thereby confuse the simple objectives of the Act: to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. The arguments run that the objective is "unrealistic" and "unreasonable." We cannot, they say, live on earth without violation of the objective. That, perhaps, is true if we take a slavishly narrow and prejudicial interpretation of the phrase; but neither can we live in progressive comfort and wealth if we allow accumulating worldwide intrusions on the physical, chemical, and biological integrity of the earth.

And so we are asked now to dissect and define a phrase that should not be dissected. Our interest is in the preservation of the biota including man. The biota is dependent on the physics and chemistry of environment and affects both. In this case all is one and one is all. A dissection is inappropriate.

There is, unfortunately, no universal agreement that the preservation of the biota is in the interests of man. The oil companies can and will buy the fisheries in a time of growing hunger and assert that the world is improved. And if biotic resources are important, they say, which ones? I cannot repair in 5 minutes the accumulated effects of a half century of educational perversion in science. I can but assert that the essential qualities of air, water, and land that make the earth habitable for man are maintained by natural ecosystems in a late stage of evolutionary and successional development. We are now watching regional and worldwide changes in these systems, caused by man, that threaten all. The 1972 Amendments are an acknowledgement of that fact and a step toward recognition in law that the biota provides a series of essential services in addition to food and fiber. The question comes back now: how can we best interpret and strengthen this important law? What new in science can we bring to bear on EPA's job of supporting the law?

The answer is that science can help powerfully, if it will. It will not help powerfully if it acquiesces in the popular belief that compromise among competing exploiters is a sufficient basis for management of the Nation's waters; that all waters have an assimilative capacity for all wastes and management is a simple matter of dividing this assimilative capacity among the users. It will help if it starts with basic principles of science and builds enduring management plans on them. The two most basic principles are evolution and succession. I shall emphasize the latter.

The generalized effect of human activities is to shift both terrestrial and aquatic systems from successionally mature stages to less mature, successional, or "managed" stages. We ask what happens to water when such shifts occur. We recognize that the qualities of lakes and streams are closely coupled to the qualities of their drainage basins and that the "integrity" of a river's functions reaches far beyond the water to the land it drains. How does this water change as the land changes? There is no simple answer; we can, however, examine the concentrations of major nutrient ions in waters draining ecosystems that have been disturbed, such as has been done at Hubbard Brook and elsewhere. Even better we can examine the flux of nutrients along a sere, one unit succession from agriculture to forest within the Eastern Deciduous Forest. The sere I shall use as an example is that leading to oak-pine forest in central Long Island. In this instance, Dr. Ballard and I have measured the quantity of nutrient ions entering the ground water under the various communities of the sere. This ground water flows. On Long Island it flows about 6 inches per day and goes ultimately into ponds, streams, and estuaries along the shore. It is, in addition, a major source of potable water. It is kept flowing by an annual percolation of about 55 cm. How do these plant communities change the qualities of the precipitation as it passes through them to become part of the ground and surface water system?

The flux of anions and cations through these systems is shown in Figure 1. Two trends are conspicuous: first, for most of the ecosystems the effect is to increase the flux of most ions over that in precipitation, despite the high ionic content of New York rain. The ecosystems are net sources of most ions.

Second, the fluxes out of these systems are substantially higher in the younger, least mature successional systems; they are least in the later, forest stages. The difference is especially conspicuous for the nitrate ion where the difference between agriculture and oak-pine forest was more than 1,000 fold, but it applies to virtually all ions except PO_4, which moves little under such circumstances.

The sources of the additional ions include fertilizers applied in agriculture and the erosion of primary minerals. The accumulation of nutrients in the net ecosystem production of the rapidly developing successional systems is not sufficient to absorb the nutrients available—and they are lost, to contribute to the eutrophication of water bodies.

If we ask what the ionic flux into the ground water and therefore into streams was prior to the shift into agricultural and successional ecosystems, we find it under the present forest ecosystems. The quality of the water under these communities gives us the best approximation of the nutrient ion content of "normal" water entering lakes and streams in this region. This is the quality of water required to support the mature, evolutionarily-derived aquatic ecosystems of the area. These are the longest lived, least fluctuating, most predictable. While they may not be the most productive of organic matter, they offer a wide range of resources to man, not the least of which is water of high and predictable quality.

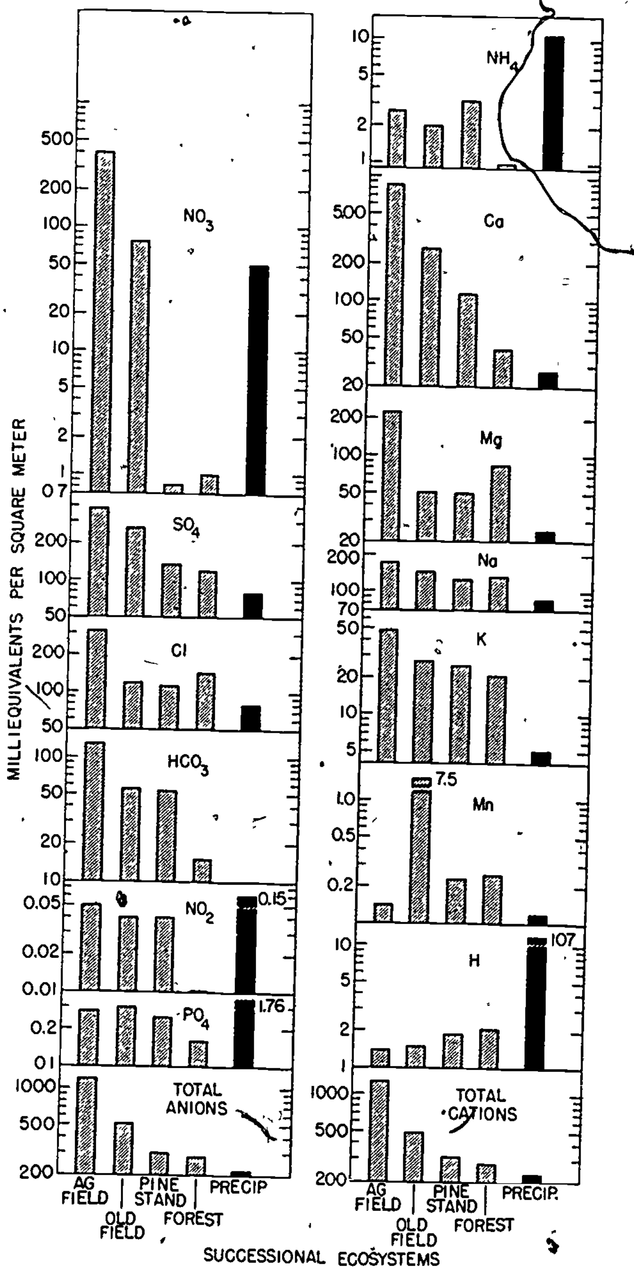

FIGURE 1

Economists and other practical men bridle at the suggestion that management of environment should favor evolutionary and successional maturity. What about cities, agriculture, clear-cut forests, and human wastes—not to speak of toxins such as DDT?

The answer is simple enough; this is the cost of intensive use of environment. We have already moved far toward recognizing the need; we have acknowledged that certain toxins such as DDT, aldrin and dieldrin are intrinsically uncontrollable and cannot be used. In effect we have said that there are aspects of technology that we must forego to live safely together. It is a small further step to accept that industrial wastes are not appropriately made a public responsibility for disposal; they are a part of the cost of industry and to be contained within it.

Similarly, we are faced with the challenge, still poorly recognized, of building closed urban and agricultural systems that mimic in their exchanges with the rest of environment the mature natural systems they displaced. Here is the current challenge for science and government—not to aid in the diffusion of human influences around an already too small world, but to speed the evolution of closed, man-dominated systems that offer the potential for a long, stable, and rewarding life for man.

Unreasonable? Hopelessly idealistic? Perhaps, but only if we reject at this late stage the age-old, time tested precept of other reasonable men: *Sic utere tuo ut alienum non laedas.*

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Research carried out at Brookhaven National Laboratory under the auspices of U.S. Energy Research and Development Administration.

DISCUSSION

Comment: I wonder, Mr. Woodwell, if you could comment on some ideas on closed urban and agricultural systems? I wonder if you have any further ideas on it?

Dr. Woodwell: Do you mean how do we close them?

Comment: Yes, and what the elements might look like.

Dr. Woodwell: Well, we start with sewage systems. At the moment, many cities are building sewage outfall pipes that will dump sewage, fresh water, and other wastes into the coastal oceans.

That procedure seems to me to be totally inconsistent with the generalized objective stated by the law we're here to discuss. There is a very serious and important challenge to science and government to figure out how to recover the fresh water in sewage and use it again; to recover the nutrients and other wastes; to avoid the inevitable pollution of the coastal waters if those wastes are dumped there; and, to improve the patterns of use of fresh water and nutrients. Another enormous challenge is to figure out how to avoid dumping toxins such as oxides of sulphur and nitrogen into the atmosphere to acidify rains hundreds of miles from the source.

There always are the costs of increasing population and increasing intensity of land use. The alternative to progressive degradation of the environment is to close up our systems. If we are willing to reduce the earth's population to the point where we can live with the open systems that we've had, we can rely on dilution and the well-established concept of assimilative capacity to restore the stability of the resources that we're using.

Comment: Would you describe the Brookhaven experiment in closing that loop, both from the kinds of problems you encountered and convincing people it would be a good idea, plus some of the technical problems that you ran into regarding the use of the land?

Dr. Woodwell: I suppose that one has to do as one says. Over the past several years, we've built at Brookhaven a series of experiments designed to explore the possibility of closing that sewage loop with the hope that we will make it unnecessary to have offshore disposal of Long Island's waste.

The approach that we used was to start with what we thought we knew. We thought we were experts in water and nutrient cycling in terrestrial and aquatic systems. So we approached the question as to whether we could build a combination of natural and manmade ecosystems for recovering water and nutrients in sewage from the Brookhaven Laboratory sewage treatment plant.

Unfortunately, Brookhaven National Laboratory is a scientific community and it doesn't have very dirty sewage, so we had to get dirtier sewage trucked in. We made special blends of sewage, one the equivalent of the effluent from a primary treatment plant; the other the equivalent of the effluent from a secondary plant.

The plant communities used were the sere from agriculture through to a late-successional forest. We've also used a series of marshes and ponds and meadows to examine the potential of these systems as well, for recovering water and sewage.

To put the story in a nutshell, it is still incomplete, of course, but we now are beginning to remember things. We know that from the standpoint of versatility, certainly agriculture is the best way to absorb nutrients and manage the ground water in terrestrial communities, but other natural communities have a certain definable potential.

The most promising communities are the aquatic ones, the meadows, and the marsh and pond complex. It looks as though we can use a combination of marsh and pond. We built a marsh, most successfully; we built a pond lined with plastic to separate it from the ground water, and the edges of this pond are large plastic pans that support manmade marshes.

It looks as though sewage trickled into these marshes, then into the pond and recirculated. It is really cleaned up very rapidly. This is quite a promising technique.

The point I make is not that there is a single answer to the set of questions I have set forth, but that there are several answers. The answers are likely to be complicated. These that I have outlined here seem to offer one set of possibilities that, by and large, aren't being explored in detail or with great intensity.

We have had no support, for instance, from EPA for this bit of research, although it's a fairly large project, amounting to several hundred thousand dollars a year. It has been financed, interestingly enough, by the old Atomic Energy Commission and by the local government; the town of Brookhaven, Long Island, which has a quite remarkably progressive Republican administration, and has had the foresight to invest very heavily in this kind of research and is learning a great deal from it. I believe they feel rewarded.

I believe that there is in this sort of approach to the sewage problem and to the problem of closing the loop, a need for very great efforts in environmental science, which really changes the direction, the entire objective in the management of the environment.

That is what this law that we're discussing asks us to do. It makes the assumption that we can live on earth only if we preserve the essential integrity of the physical and chemical and biological functions of the environment. That if we continue to allow human influences to diffuse further and further around the world, and with greater intensity, we will destroy those essential functions, and make the world less habitable for man.

So I see here a challenge that just plain isn't being met, by and large, by current research. Current research on energy in big national laboratories such as the one I work at, are focusing on what have been the objectives of science for the past decade, to relieve the expansion of present patterns of industrial and economic activity—further diffusion of human influences rather than the consolidation of those influences into fairly tightly built systems.

Comment: In your artificial system, I should say your natural system for removing these nutrients, picking them up in another marsh plant is not closing the loop, is it? Do you have a plan for getting those bull rushes back into cows?

Dr. Woodwell: Ideally, of course, one would put them back into agriculture and recirculate them through civilization, but that's hard to do with sewage because we have certain problems with parasites and toxins of various types.

What one can do, however, is to concentrate those nutrients in a place where they can be harvested and reused. They can be used ultimately as fertilizer in agriculture; humus can be moved to agriculture; if there are heavy metals, as there may be in some types of sewage these days, the heavy metals tend to be deposited in the marsh sediments. Then after a time, those sediments can be harvested and treated in whatever way one wants. That seems to me to be a lot better approach than we're using at the moment, allowing them to be dispersed into coastal oceans.

Chairman Guarraia: Isn't it a fact that this approach has been taken at Woods Hole with some of Dr. John Ryther's work with agricultural utilization of sewage?

Dr. Woodwell: Yes indeed. He has a very elaborate, large project in which they're exploring the possibilities of using marine organisms, plants, filter feeders, and marine animals, to scrub the nutrients out of sewage.

It has the disadvantage, of course, of still resulting in the loss of the fresh water; the fresh water is mixed with saltwater, and then lost. It has the advantage that the water that's released is low in nutrients. They can do all this with a very high degree of efficiency.

Perhaps Dr. Ketchum would like to comment on that.

Dr. Ketchum: I think you've stated it properly and adequately. I think it's worth mentioning the Penn State studies in which they have fertilized agricultural crops. It's not uncommon in the West in irrigation processes.

Dr. Woodwell: Yes. I haven't mentioned a thousand other projects that have been carried out over the past decades—some of them have gone back even centuries—in which sewage has been used in parallel approaches.

I think that we have the advantage at the moment of having learned a lot about the structure of ecosystems and the circulation of nutrients. It's useful to put this theory and detailed knowledge into practice.

Comment: The thing that we're hearing now with regard to returning the sewage to its natural system is the possibility of not only returning it to its natural system, but contaminating our source of ground water, which is underneath that natural system and never was exposed to these pollutants in the first place. Especially, some of the concern raised about the problem of chemicals in the surface water. People are inclined to turn more and more to the ground water for their drinking source.

Is there any way, at least in a temporary sense, that you can get the waste back on the land without getting the ground water contaminated as well?

Dr. Woodwell: I think so. I think the most common problem, at least in my experience in Long Island, is with nitrogen-nitrate, in particular.

There are various ways of removing nitrogen. The meadows that we're working with are very, very efficient at removing nitrogen, removing well over 95 percent of it; so do the ponds and marshes.

So if first treatment involves trickling through a meadow or passage through a marsh and pond, we wind up with very low concentrations of total nitrogen.

The heavy metals that concern many of you, I suspect, tend to be sedimented in the marsh and in the meadow, as well. So they are localized and not transported.

Comment: Have you been able to trace any of the more exotic viruses that have shown up? For example, in the EDS studies?

Dr. Woodwell: No. That's one of the failures of my program at the moment. It just hasn't been done.

Comment: It's not that it can't be done; it just hasn't been done yet.

Dr. O'Connor: I'm sure that most of us with reasonable intellect subscribe and agree with the principles you've enunciated. I guess our problems arise, not so much in acceptance of those basic moral issues, as in answering specific problems while we have such short time here for ourselves and our future.

In this sense, I guess I have to disagree with some of the things you said, or maybe add to them. Let me first try to add something and then disagree.

I would add one other aspect to your fine talk; it is incorporating flexibility into our environmental planning. Let's not lock ourselves in too strongly, as with returning things to the Great Lakes. If we mess it up, we're going to mess it up for years.

It's precisely on that basis, getting more directly to our home area, that I disagree so strongly with some of the components that I think you and others have agreed upon; returning the treated effluent of Long Island to the ground water is exactly the last point you raised.

Whereas, if we do return to the ocean for a short time, we have two potential advantages. One is the flexibility—we're not locking ourselves into potentially destroying a water resource. Secondly, the return of nutrients to land, as you implied, can be equally beneficial to sea. It's an extension of what you said. Therefore, I think one would be a little hard pressed to argue strongly for returning it to ground water.

Dr. Woodwell: By the time we have built a, roughly, billion dollar sewage collection system treatment plant and a sewage outfall pipe that costs about $60 million, one hardly thinks of this as an easily reversible, flexible sewage management system.

The investment of $60 million for a sewage outfall pipe is sufficient capital investment that I just don't think that we're going to change that plan in a hurry.

Going beyond that to pursue the flexibility aspect, it is true that we can increase the primary productivity of limited areas in the ocean by adding nitrogen compounds and phosphorus to them. And, it's also true that the coastal oceans have a certain assimilative capacity for organic matter and other human wastes.

But it isn't true that they have an assimilative capacity for all toxins. Most people these days agree that we don't have room in the oceans for persistent chlorinated hydrocarbons such as DDT and PCBs. It's very hard to keep those out of the sewage of New York, for instance.

So, while we might establish the idea of an assimilative capacity for certain substances in sewage, that assimilative capacity doesn't apply, generally, to what comes with that sewage. Is that true?

Dr. O'Connor: Quite true. As I suggested this morning, I'm not referring to the principle of assimilative capacity, but the one that you enunciated yourself, that is the residual materials in the treated effluent are good for the land and its natural recycling system. I'm simply submitting that they could be equally good for the water in a natural recycling system.

So, the option is open both ways. I would add one other point. Just as hydrocarbons are bad for the ocean, I would say, considering the groundwater resource and the use we make of it in Long Island, it is doubly bad for the return there.

Finally, just a little rub. I'm glad to see you are conscious of forces.

Dr. Woodwell: Very good. I think that the possibilities of handling sewage on land are very great. It's hardly inflexible. We have physical-chemical systems for sewage treatment; we can take out chlorinated hydrocarbons and not put them into the ground water. In fact, it's very hard to get them into the ground water because they tend to be absorbed in places on the surface of the ground.

One of the best, the classic approach to physical-chemical treatment is, of course, with charcoal filters of various types. The humus layer of forest, or the organic sediments of the marsh or a meadow, come very close to being precisely that. They pick up virtually everything.

So, I think of the terrestrial and aquatic, as opposed to marine approaches, as being extremely versatile, and not fantastically expensive.

Dr. Patrick: I just wanted to clarify one point which you raise. That is, in order to keep sewage from getting into the ground water, the Campbell Soup Company did a remarkable piece of work in which they put tiled drains under their spray irrigation areas, and these tiles collect the excess that runs down and is not picked up; and that is resprayed or put into a pond, and it is then acted on by algae.

Dr. Woodwell: Very good, Ruth, thank you. I think I can guarantee that I can produce a system for absorbing nutrients and toxins on the surface of the ground that will not result in contamination of the ground waters.

I see heads shaking. I can see that we have a lot of research to do.

Comment: The concept of land disposal of sewage is not particularly new to this world. I mentioned yesterday the CSEOLM Study of the Chicago District of the Corps of Engineers done about a year ago. CSEOLM was an acronym for Chicago South End of Lake Michigan.

What they were looking at was the sewage and flood water in the entire metropolitan Chicago area. One of the proposals made in this study was land disposal of all of the wastewaters from the metropolitan Chicago area—something very much along the lines that you discussed.

One of the things from which the proposa[illegible]fered was that the land that would be required for this wasn't measured in acres, it was measured in counties. It would have required, I can't tell you off the top of my head, how many millions of acres, but as I recall, it was measured in millions.

Do you think it is a wise way of utilizing our land resources to put enormous land areas under this kind of what might be called stress?

Dr. Woodwell: To answer that, I suppose we ought to take a quick look at what we do now. What we do now, of course, is to partially treat this waste. If we're in New York City, we then release it into some water body that connects to the New York Bight, losing the fresh water for any new, immediate use; losing a good fraction of the nitrogen and phosphorus, the nutrients; and, without question, polluting the coastal waters.

In addition to that, there are certain hazards connected with dumping this partially treated waste into coastal waters. Coastal waters are indeed degraded by this process over large areas, so there is a cost which we don't calculate at the moment or enter into the calculation of what it takes to run a city.

In addition to that, we generate large quantities of sludge which are, in New York City, hauled out in special barges into the New York Bight and dumped. And you EPA people know that this is an increasing problem.

That's what we do right now. Now the alternative to this, at least what I'm saying is an alternative, is to do research on how we recover the water and nutrients, keeping them on land and restoring the water to a usable condition.

If it takes a large land area, that, unfortunately, is the cost of intensive use of the environment. I see that as the only way in which we can intensify the use of environments otherwise degraded. We lose the coastal fisheries, and almost no one is saying these days that we ought to do that.

Comment: Given that there is a large land requirement probably involved with your marshes and meadows, how does this system stack up in terms of their normal ecosystem productivity? In other words, can birds and animals that would characteristically be found in marshes and meadows, survive in these artificial waste treatment systems and would they survive? Do you have any experience on that yet?

Dr. Woodwell: It's a little premature, I suppose. The marshes that we have built are attractive to ducks and geese and great blue herons; certainly the ponds support fish. I don't see any reason why these experimentally enriched systems can't be a part of the matrix of natural systems that are the general environment.

Dr. O'Connor: There was one other point that you raised that I would like to address.

I understand your prerogative to speak and put in a black and white fashion the conflict between the environmentalist and the industrialist. Certainly one can subscribe to the principle of your point. I think it's unrealistic, as I tried to say this morning, given the fact that we live in a technological, industrial society.

To address the issue, in my mind it's simplistic, that you're going to change the structure of society. Now, I fully agree with much of that, and our standard of living. But it seems to me that the issues are not so much between the environmentalist and the industrialist as with all the other basic needs society has. There's a conflict of those monies to alleviate poverty; there's a whole priority of social needs that have to be put into perspective with the environmental. And I think that is a more critical issue.

Dr. Woodwell: You put your finger on the very core of what concerns ecologists, scientists of the environment, at the moment. It's a very large topic, one that isn't easily examined in detail in a moment.

The question comes back as to what are the fundamental resources in support of man? What does it take to keep us on earth? We in the Western world tend to think that it takes a healthy economy, fed by lots of fossil fuel energy, and that nuclear energy is going to displace this, and that the technology that's built on this free flow of fairly inexpensive energy is going to solve all the problems of man. That is simply not so in the eyes of biologists who study environment.

We have heard in great detail about the changes that occur in the rivers with channelization; that as soon as we channelize the river, the normal functions of the river that were performed by biotic systems are taken over by man, at considerable cost. As a result of the channelization, the depth of floods increases. Sediment loads increase and a whole new array of problems appears that requires another tax on the general public to resolve.

That isn't different from other aspects of the environment where we gradually take over management from biotic systems. And we aren't very good at that kind of management. If we were good at it there wouldn't be a problem in channelization, there wouldn't be a problem in management of the coastal oceans or in management of lakes.

Dr. O'Connor: I agree we are no good on it. We have very little experience or background, so we will accept the principle of flexibility then.

Dr. Woodwell: I'm not sure what I'm accepting. So we come back to what our basic resources are. Our basic resources worldwide are not energy or the economy or anything else. The basic resources are biotic resources. These are the resources that are used by all of the people on earth, all of the time.

Much more energy flows to the support of man through biotic resources then flows through industrial systems. Much more energy, by a factor of 20 or so, at least, worldwide. It's only here in the United States, and for probably a fairly short time, that we live with the enormous wealth that cheap industrial energy has given us.

Although this gives us the opportunity to use other resources, as populations increase and demand on environment grows, we have to use our resources in totally different ways in order to avoid degrading the much more fundamental biotic resources that are essential to all of us.

That's the point the ecologists and scientists have to make, and that should be the point of research. A lot of research, right now while we can do it, on how to close up these systems and live for a long time with a finite set of biotic resources.,

Perhaps an infinite technology, but it hasn't changed the basic rules of the game. The basic rule of the game is that everybody eats plants.

Comment: I guess it's not a question, but a comment that I'd like you to say you agree with. I have a couple of observations on the story of wastewater disposal in Illinois. I think the program was victimized by a poor job of public relations there, which is typified by the description of the project as the disposal of wastewater. It's not disposal and it's not wastewater. They might have called it the recycling of essential nutrients, and told the counties involved that they had chosen the lucky number and had been chosen to receive a great deal of free irrigation water and fertilizer as a gift from the city of Chicago.

My point is that a great deal of the time a lot of the stigma involved is dependent upon what you call the thing.

Secondly, I don't think that the utilization of land resources for the receipt of these materials precludes its use for all the other things that are already there. In fact, I think it enhances it. So, it isn't like two or three counties have to move somewhere else. In fact, their agricultural space might be increased. I think that's the point of your talk.

The third point is to the gentleman over here. I recall some work we did on a marsh in North Carolina, which by accident was unlucky enough to get at the end of the pipe. It was not any sort of a treatment system, but it was that kind of marsh. It was a great deal more productive, not only in plant biomass, but also in all the other things associated with it. And one was struck by this just walking onto the sight.

If there had been, in fact, a scheme to harvest that material and do something with it rather than let it fall right back into the water and simply pass those nutrients on down, it might have been a very good and efficient way of returning that material.

Dr. Woodwell: Very good, I'll agree with all of that.

REPRESENTATIVE SPECIES CONCEPT

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The question can be asked very fairly—given all of our good intentions, given that we're honorable men and we don't want to destroy someone else's neighborhood anymore than we do our own—what do we do?

My response to this question is a pragmatic approach to assessing the impacts by either an existing or potential source of biological damage on the integrity of water quality. Essentially what I have tried to ask, not only personally but in working with people in EPA, people in the fisheries business, other ecologists, is, "Can we go about doing an assessment in a way that is reasonable, come up with some good criteria for the managers?"

Basically, it involves selecting from the environment in question several key species that we're going to use as key indicators or determinants in terms of criteria for decisions based on water quality. These are species that could fall into two categories: representative species and what we might call those important species. Different agencies have used this concept in different ways and I hope I can bring some of the salient points together.

In essence, the approach is one of selecting certain important and representative aquatic species to be the critical indicators for decisions regarding the particular ecosystems and location being evaluated. The opposite approach (although there should be intergradations and mixtures of approaches in practice) would be to consider only characteristics of the whole ecosystem, that is, the aggregate of thousands of diverse species and kinds of organisms.

The Representative and Important Species (RIS) concept is different from the old "indicator species" concept once used in organic pollution studies. That concept sought to identify certain undesirable, pollution-tolerant organisms (e.g., sludge worms) whose presence indicated pollution; the RIS emphasis is on those species which we want to protect or enhance.

Assumptions and Criteria: What are my assumptions in suggesting the direction of using representative and important species? What are my criteria for selecting them?

(1) It doesn't seem possible to adequately study every species that may exist at a site of pollution or other impact; there isn't enough time, money, or expertise, and most important, I don't believe the state of knowledge of aquatic ecology allows us to see all the interactions among species that may be relevant to the particular source of impact. Since all species cannot be adequately studied in the time frame for making resource decisions, some smaller number will have to be chosen.

(2) The species of primary concern are those causally related to the sources of impacts. To be sure, there may be repercussions throughout an ecosystem if certain elements are destroyed, but generally the most obvious change will be on the species directly affected. If we are to correct mistakes, we must also be most concerned with causal relationships.

(3) Some species of fish and invertebrates at a site will be economically important in their own right, that is, commercial and sports fishes, regardless of any more academic connections to the ecosystems as a whole. Some others may be nuisance species and thus important in the negative sense. Both types of species are important in a societal context; segments of the human society are particularly interested in them.

(4) Some species are known to be critical to the structure and function of their ecosystem, either through physical form, for example, corals, or through food chain relationships. These would be "important" in an ecological sense.

(5) Some species which we can term "representative" will be either particularly vulnerable to the source of potential damage (based upon our prior knowledge from laboratory or field studies), or they are truly representative in their biological requirements of most other local species. If these species are protected we feel that we can reasonably assure protection of other species at the site. Generally, we would not want to select wide-ranging species at the extremes of their geographic ranges as "particularly vulnerable" or "sensitive" representative species; they could, however, still be "important" and selected on that basis. Orga-

nisms at the edge of their range will often be the most sensitive to environmental stresses and could be useful as sensitive indicators of ecosystem effects. However, they often are of trivial importance to either the ecosystem or man in their marginal environment.

(6) Often, the list of organisms that might be considered "important" or "representative" is still too long to be practical and a smaller list, perhaps greater than five but less than 15, may have to be chosen. Generally, we would want the reduced list to include a diversity of the more sensitive fish, shellfish, or other species of direct use to man or important for structure or functioning of the ecosystem.

(7) Finally, there is a category of organisms officially listed in accordance with the Federal Endangered Species Act of 1973 (PL 93-205) which are automatically "important" by legal definition and which must be carefully considered in any environmental evaluation.

Developing such a list presents an acute test of managerial skills for the responsible agency. The key phases will be soliciting recommendations from a wide variety of sources: fish and game agencies, conservation groups, regulatory bodies, the affected industry, and others, and obtaining their understanding and acceptance of both the selection process and the end result.

Use: How will a list of representative and important species be used? A clear statement of the objectives for such a list should, of course, have preceeded its selection. The list and its use will depend upon the type of facility being evaluated.

It is useful to outline a decision train or action plan associated with our species list. My own experience has been heavily oriented towards power plant impacts, so the following thoughts are drawn from that context. The decision train I outline includes steps leading up to the selection of the list of species, and it assumes that the source of damage is not yet operating so that impacts must be predicted. If the plant is already operating, then actual damages should be looked for, and if found, then the decision may be to take actions to alleviate the damages or, if no other recourse is available, to close the plant.

Decision train: (1) Review the biological problems that have been identified at operating power plants, in laboratory studies and speculative analyses. A simple "shopping list" can be of great value in reminding the analyst of what he should be watching for.

(2) Examine the biological resources and any existing management objectives for these resources at the site.

a) If these have already been established and catalogued by resource agencies or by previous ecological studies by the company or other groups (for example, universities), then these data might be used without conducting additional field surveys.

b) If suitable data are not available, then a survey covering a minimum of 1 year is probably necessary to establish the kind of ecosystem being dealt with.

(3) Decide what problems viewed in the first slide or identified from the local resources are to be considered further for this site. In particular,

a) Is the problem credible (documented, a problem elsewhere, a good prediction)?

b) Is the problem likely to be significant for the ecosystem or society?

c) Does the species that could cause the hypothetical problem actually occur at your location, even during short periods of a critical life stage?

d) Is the species likely to be closely involved with the source of damage?

(4) On the basis of anticipated problems, decide on a list of representative and important species requiring detailed field and/or laboratory study and analysis leading toward administrative decisions. Use the assumptions discussed earlier or any other criteria that may be particularly applicable to your site.

(5) Obtain literature and laboratory data on the representative and important species. To the extent possible the analyst should become familiar with every aspect of the population dynamics of these selected species. Where data permit, population dynamics models may aid in determining which types of information are most important. Some experimentation may be necessary at this point to define such parameters of direct biological effects as lethal temperatures, upper temperatures for growth, optimum growth temperature, et cetera, that can be useful in evaluating impacts.

(6) Obtain detailed field data at the site of probable impact (and reference areas) on the RIS that would pertain directly to the anticipated problem(s). The actual distributions of the organisms at different times can be especially important. This may require more than 1 year of data to establish yearly variations.

(7) Develop engineering designs for the proposed facility to minimize problems. An example would be selection of the location for a water intake either along shore or in deep water based on the relative abundances of organisms that could be drawn in along with the water and damaged or killed.

(8) Decide (a) what problems remain credible

after compensating with good engineering and (b) the magnitude of the problem in relation to maintaining a balanced indigenous community. A projection must be made at this point from the well documented analyses on representative and important species to the likelihood of ecosystem effects. This we must accept as educated speculation.

(9) From the list of predicted significant problems that remain, or lack of them, decide upon issuing approval for the facility. The realistic ecological analyst must realize at this point, however, that there will be other considerations entering decisions besides his own.

Conclusions: Decisions regarding water resources must be made. We cannot wait for all pertinent information to come in, for in practice it never does. Knowledge continuously builds, sometimes to reveal our triumphs of insight, sometimes to reveal our mistakes.

I feel that we can minimize the latter within the practical limitations of today's environmental sciences if we concentrate our efforts on those species that we feel are either particularly important or are representative indicators of the rest.

Whether the ecosystems be designated as wild or managed (and most water bodies are actually managed for certain harvestable species), knowledgeable scientists and managers ought to be able to compile a list of key species based upon management objectives. These species can then receive more than haphazard attention. The detailed information developed on them will provide clearer decision criteria for the administrator and clearer standards for later judging of any changes in the integrity of our waters.

Let me summarize with the benefits of what I think is the concept of representative and important species. We want to do what can succeed with today's knowledge. We don't want to do a job that's going to wind up in a lot of fuzziness that's not really going to do anybody any good. We want to do something that's going to contribute to the decisions that have to be made. We also want to give those species that the public considers important more than just haphazard attention. For instance, if we had not worried about the striped bass in the Hudson Estuary area, somebody would have been down on our necks very fast.

The species that the commercial fisherman, the sports fisherman, the general public feel are important to them, often in tangible ways, these are the ones that the analysts have to consider in detail. We want to give clear criteria to the administrator. We don't want him to have to make the subjective judgments in the end. The ecologist needs to be able to lay out as clearly as he can the criteria to be used in making decisions and the alternatives. I think this system allows him to.

Some well understood standards must be put down on paper for use in judging changes that occur. By setting the criteria fairly specifically for particular representative and important species, by having population dynamics models that make predictions about what the population is going to do 5, 10, 15 years down the track, we impose our particular impact. We'll have some standards that then can be used by regulatory and conservation agencies and the general public, to know if, in fact, the decision that was made was the correct one or the best one.

There are probably other benefits too; perhaps one of them being that ecologists are maybe lazy like everybody else and we don't want to have to solve all the world's problems all at once.

DISCUSSION

Dr. Patrick: I certainly agree with you. I agree that we must understand life cycles, that we must go in depth to understand certain species. I think when you're dealing with thermal effluents perhaps you are safer in selecting a few species.

But, I should like to point out that you can have an increase or imbalance in nutrients that would bring about a change, a gradual change, a shift from a high predator pressure to one that's very low predator pressure, and you wouldn't pick it up for a long time from the kind of studies that you outline.

Except that you did give yourself an out when you said the ecologist should pick the important species. Now I feel in any such baseline studies it's important to study those species that are important in the food way as well as those that are commercially important to man, and a mix of these studies that gives you the best, shall we say, baselines for a future comparison.

Certainly I agree with you that you have to take the engineer into it with you. In the study that we did with the Chesapeake we were able to show the company and the engineering firm that a half a foot per second would greatly reduce the fish and other larger invertebrates.

And also by studies we were able to show where to put the intake that had the least fouling problems, and I'm glad to see this is working. In other words, the ecologist has really saved the utility or the company a great deal of money by asking the right questions and solving them in the right way.

But, as I said, I think you have to know more than just a few species.

Dr. Coutant: I can't say much to debate that. The comments I have made are most applicable, in their strictest sense, to cases where we're trying to deal predictively; where we simply don't have the long term ecosystem changing in front of our eyes for someone to go out and look at.

In practice, application of any source of potential damage to aquatic ecosystems occurs over a time span. The damage may occur 10 years from now if you're in the early stages of design of a power station. Sometimes you're at the construction phase when damages may start occurring, and then later on they are occurring more regularly and you can look at their effects.

The representative and important species approach works best for the predictive situation. Such a predictive system can evolve into the ecosystem approach which has its advantages when the system is there and is changing. Then you can look at things like species diversity and other factors which you simply couldn't look at in a predictive sense.

Dr. Ketchum: I too agree with what Dr. Coutant has said. I would like to utter just one caution, being accustomed to the natural fluctuations of the marine fish population. I just hope that you aren't on a declining part of the natural curve when you make your prediction and find out that nature has taken over and had a greater effect in that particular case than man's activities.

Dr. Coutant: A very good point. In fact, it was with some trepidation that I suggested a 1-year survey. It depends on the audience that you're talking to. If you talk to a group of utility people exclusively, they throw up their hands in horror at the thought of having to conduct an ecological study for a whole year. I think any good ecologist would recognize that, as you say, there are fluctuations and long term trends that make even 1-year samplings almost worthless.

Dr. Ketchum: Perhaps studies of adjacent areas could serve as a control.

Dr. Coutant: Right. In fact, one of the points which I didn't include in the paper is that we need a better implementation of what we might call the resource agencies of the country for putting together inventories of species and their population dynamics that are apt to be on a list of representative and important species.

We know there are State agencies doing inventories, Federal agencies doing inventories, and utilities around the country doing surveys of power plant sites. If we had a system for putting this information together, the poor analyst could go to this source and determine reasonably accurately what is happening ecologically in the western end of Long Island Sound, for example. There is a good body of information from the various State and Federal agencies that could be used as a basis for predictions if it were uniformly available. But I don't think we're there yet. We don't have that amount of cooperation available in the system.

Comment: I know that the fish, or single species has been used quite a lot in the last few years. But I agree with Dr. Patrick, I think we're going to have to spread out more.

And the current work with microcosms, especially work of Bob Metcalf and others, from the work at Oak Ridge shows that they had utility and screening materials in screening impact on functional groups and functions of ecosystems where we don't have to go to the complete ecosystem and we can get some ideas with some mix, even artificial mixes.

But I think that being able to protect or evaluate the impact material on a natural nutrient cycle or some of the functions such as primary production and decomposition are as important as those species of the top level fish that we might select. That certainly would cover more than five to 15.

Dr. Coutant: I agree with that wholeheartedly. As I mentioned, you go on from the RIS approach to a more ecosystem-oriented approach. But I'd also bounce the question back to you; are we, in a sense, taking a representative and important microcosm with which to make our judgments? For the fish, which I tend to emphasize because that's what I have been dealing with, we tend to select a species.

In your case, you're interested in lake ecosystems. You, therefore, set up an aquarium that has about the right mix of water, plankton and sediment. Do you not call that a representative segment of an ecosystem?

Comment: But if we look at the important functions of an ecosystem, and put in representatives of those functions, then I think we've come a long step—being able to use something on the east coast and the west coast to represent the same functions. And we don't have to have the same species.

The people in Georgia complain about using Duluth fish because it's a cold water fish. But if we have representatives of a level of the bacteria and the algae that grow in the south and west and north and east, put these into microcosms, then we represent functions and not a particular species.

Dr. Coutant: Yes, that's true. I guess I'd have to go back to the criticism that the analyst would get from the public. For example, in trying to do that, you select a certain species—carp, for example—to put into your microcosm. You may have used this species because another species won't fit. The question you get from the public hearing may be: why did you select carp for a bottom feeder when you should have used some other species which I (the public) think is more important?

It's difficult to translate microcosm studies to the very specific concerns that people have. Microcosm studies are becoming more and more important, and they're telling us many things. But you do wind up with difficulty of translation in the end. The man in the field, the man with his fishing pole, is interested in striped bass or he's interested in largemouth bass, and in the end, you're going to have to translate your results back to the things people are interested in.

Chairman Guarraia: I'd like to make a comment here. Being a microbiologist, I guess I have to get a plug in. I'd have to subscribe to the microcosm concept that Mr. Sanders mentioned.

There have been some studies that do indicate that thermal effluents have shifted microbial populations, and I'm thinking specifically of some work with Dr. John Buck. And Dr. Blakehurst from Canada has shown that the tubifex worms have a dislike for certain species of microorganisms.

In other studies Dr. Odum has shown that fish have a distinct preference for certain microbial systems. This, of course, leads us to wonder what happens when we enrich certain aquatic environments with nutrients from various sources.

What are long term changes in terms of microbial shifts? I don't know the answer, and I don't expect you to know the answer to this. So, certainly, the single species concept is important, and I think primarily for one reason—you get a handle on it. I think we all recognize the extreme complexity of the whole relationship.

Dr. O'Connor: Would you comment briefly on the degree to which the fish population models that you referred to have been validated, if at all?

Dr. Coutant: I think both with respect to ours and just about any other model that has been put together, you have to say not enough. Validation is a most important part of any model development and it tends to be the one least looked at. Everybody puts a lot of IBM cards together and out comes a number, and we think we're God.

But, unless those results can be validated, they really don't mean much. The particular model that I showed you is a good example. It is being validated in a sense that studies are going on in association with a particular power plant. Very interesting studies and expensive studies to find the information that the models, both ours and others that have been developed for the same predictions, have shown to be important.

There are two ways of looking at validating models. One is to determine whether the coefficients are right. So a lot of work is being done now to get the right coefficients for, among other things, egg and larvae distributions for striped bass. Second, there is also a planning phase for once the impact has started. Some of that work is contributing to finding out whether each year's data tend to match what we predicted for the year.

I think validation is, in that case, coming along as well as can be expected. But often it isn't and I think your point is well taken.

Dr. O'Connor: Projecting in the research area, how close do you see models such as that in which you would introduce more specific pollution effects like toxicity? Is anyone in the fisheries area doing that now? Or when do you expect that might be done?

Dr. Coutant: That's one thing that actually we are going to try to do with the striped bass model on the Hudson, because some things are tied in—

Dr. O'Connor: Just thermally?

Dr. Coutant: Well, the first step is thermally. I showed you the population dynamics model; actually the thing that goes behind the screen for that is a hydraulics model that predicts the number of eggs and larvae that are going to be in the entrainment box. Built into the hydraulic model are the dynamics of the estuary, such that you can predict things like oxygen depletion by having thermal effluent added, a new sewage treatment plant or other additions. Really, what we would like in the end is to have a Hudson River resource model.

Dr. O'Connor: We should get together some day.

Dr. Coutant: I'd like to make one point. Your question mentioned the research context. In our discussion I'd like to make clear that I'm talking fairly pragmatically in this representative and important species context, about things that we feel we can do now; as opposed to things that I'd like to be able to do in the future. There are a lot of things that we ought to be able to do in the future if we keep up a good level of research effort.

Dr. O'Connor: Let me just add, when you get to the DO studies, and you look around at the engineers, that we introduce alternatives as best we can.

Dr. Coutant: The business could stand a lot of cooperation.

Comment: You said at the beginning that you were interested in approaching these in as much of a pragmatic way as possible. I'd like to see if you can give any kind of estimate of the types of expertise needed and therefore the money and manpower. We realize that when you're talking about a nuclear power plant you're talking about a lot of money over a long period of time. But can you make any application from your studies to something not as costly?

Dr. Coutant: I'm not going to try to go into numbers. I think if we've learned anything in this exercise on the Hudson, and also working on the Columbia, we've learned that we tend to greatly underestimate the time it's going to take, the money it's going to take; we tend to overestimate what we're going to do.

To do the job right, even for one species like the striped bass on the Hudson, you don't write an impact statement in 3 months. It takes several years to do a good job and then you don't know for sure where you are really, because you can't put confidence limits on your prediction.

So, I'm forced to say let's get more pragmatic. When we try to look at what we can do let's be very critical of what we think we can do, and let's be very narrowminded in this sense—that we're practical in selecting the number of species. This also puts pressure on those who are selecting this list of representative and important species to do a good job in making the selection. Because you're going to have to spend a lot of time, money, and effort on the few species that you do select.

Dr. Woodwell: I must say I also approve of your presentation and your approach in general, but lest the baby be thrown out with the wash here, you haven't said what you discovered as a result of all that study of the striped bass in the Hudson and what the conclusion might be.

Anticipating your answer to that, I'll go on to say that the problem will then turn out to be not striped bass in the Hudson, but the fact that one of those nuclear plants puts through itself 30 million gallons an hour, or more, almost an inconceivable quantity of water. And, 10 or 12 or 16 of these plants are proposed for the Hudson River estuary.

It really isn't the striped bass that we're interested in, but the Hudson River estuary ecosystem. And right on the face of it, we know that we can't put that many plants on the Hudson River estuary without substantially destroying it in the beginning. Then what do we do.

The question then comes back to, do we allow this further diffusion of human influences around the world, or do we decide that the estuaries are important, and we can't put reactors on them, that we have to figure out something else to do with reactors.

Dr. Coutant: I don't want to make this an inhouse joke in a sense. For those of you who aren't familiar with what we have been talking about, let me explain, off-the-record.

(Discussion off-the-record because regulatory action still underway.)

Dr. Patrick: I think two different questions are posed here. One is what's going to happen to a species that's important to man; the other is, what is going to happen to the assimilative capacity of the ecosystem, or its flexibility over time.

I would like to find that when you study the major groups performing functions in the ecosystem, the problem which Dr. Ketchum brought up about the variation due to nature, the populations of a central species, doesn't necessarily happen, at least in all the rivers that I've ever studied.

You don't have, under natural conditions, all aspects of the ecosystem varying the same way. So you aren't led astray by a minimum number of specimens of a given population being characteristic of the area. I'd also like to point out that we have been able to monitor some facets of the ecosystems.

IDENTIFYING INTEGRITY THROUGH ECOSYSTEM STUDY

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Natural aquatic ecosystems have evolved over time to accommodate to the physical and chemical environment in which they live. This paper will discuss the basis for the integrity of these systems, how perturbation affects them, and will make suggestions for strategies of management to reduce the effects of perturbation or pollution; that is, in most cases, pollution.

This discussion will concern itself primarily with streams and rivers and will be based largely on my experience of studying streams in the eastern part of the United States.

Studies of stream ecosystems indicate they have optimized the channel structure and the variable chemical and physical characteristics of the water due to seasonal change, runoff from the watershed, and downstream flow. For example, in the headwater sections of the stream the structure and functioning of the ecosystems are responsive to the riffle-pool sequence which is composed of a diversity of substrates, mainly rocks, rubble, pebbles, sand, and some silt which resides either in the pools or along the edges of the stream.

The diversity of the current pattern is high and is responsive to the riffle-pool sequence and the roughness of the stream bed. The water is derived in varying proportions depending on the stream from the ground water and from the runoff from the watershed. In undisturbed water, ground water mainly contributes the nutrients such as calcium and magnesium which reflect the geology of the area from which the ground water is derived. In contrast, the runoff from the watershed reflects the usage of the watershed. In undisturbed areas it will often reflect the organic matter produced by the trees and vegetation, whereas if the area has been utilized by man it may reflect agricultural activities, roads, and other such results of man's activities. It is difficult to differentiate the contribution of these two sources because, after all, the runoff from the watershed may reflect the ground water and likewise the ground water may reflect the usage of the watershed.

Head water: In headwater streams detritus is one of the main inputs. This is because these streams usually run through heavily forested areas and the fall-in of leaves and insects living within the trees produces a considerable detrital input over the year. Also, the trees of the watershed modify the light entering the stream and prevent extremely high temperatures from occurring during the summer months. The temperature of these headwater streams may be fairly constant if most of the water is derived from ground water and is heavily shaded, or may fluctuate more extensively if considerable amounts of the water are from surface runoff and if the trees have been cut away from the banks of the stream.

These headwater ecosystems have evolved to have great dependence upon detritus in the late summer, fall, and early winter months and to depend upon primary production in the late winter, spring, and early summer months. Of course, in those areas where the forest has been cut away and the direct sunlight enters the stream, primary production by algae and aquatic plants is the main base of the food web.

In these headwater streams the flow is relatively small in volume and because of the vegetative nature of the banks the water is typically clear. As a result, the photosynthetic zone extends completely over the stream bed. Many of the aquatic insects which live in riffles have adapted themselves to the high rates of flow that exist in these areas and thus have streamlined bodies. Fishes often develop suction discs by which they can attach to the rocks. Some diatoms will have a much more streamlined shape or develop strong holdparts in swift-flowing water compared to their shape and manner of living in slower moving waters or pools.

In the slackwaters below riffles we typically find many filter-feeding organisms. Sometimes these also exist within the riffle proper as in the case of blackfly larvae, but caddisflies, clams, and other filter feeders are more typically found in the slackwater area where the current is still fast but not as erosive as in the riffle proper.

In the pool one typically finds organisms that do not like high flow and prefer a fair amount of organic matter as a nutrient source. Thus, in the sediments of pools we typically find chironomid larvae and tubificid worms. Also living in pools we often find fish and crayfish. The types of species found somewhat depend upon whether the pool is well oxygenated all the way to the riverbed or whether there is a decrease in oxygen in the lower part of the pool. In headwater reaches of the stream the lowering of oxygen typically does not occur in pools. This characteristic may occur in deeper downstream pools. Roots of bankside vegetation often trail into the stream and in these we often find water beetles, damselflies, and sometimes salamanders.

Main trunk of the river: As one proceeds downstream the flow increases in volume and the water becomes more muddy. In this reach of the river the meandering pattern becomes much more eccentric and the riffle-pool sequence disappears.

Habitats for aquatic life are mainly on the shoaling edges of meanders; very little lives within the cutting edge of the stream. Trailing branches from trees along the banks of the streams and the debris caught among them often form habitats for aquatic life. The advantage of these habitats is that they float up and down with the increase and decrease of flow and thus do not become submerged, as do habitats on stable subwaters.

Because of the large volume of flow, shifts in height or depth of the water may be very great and sudden, particularly during the spring of the year. This section of the stream is usually accompanied by a wide flood plain, parts of which may be wet swamps all during the year and in other cases, flood plain ponds develop. These areas with much more stable beds are used by many aquatic organisms as feeding and nursery grounds. One has only to observe the teeming life in these flood plain ponds and swamps to realize their importance in seeding the main channel of the river. During high flows in the spring and sometimes in the fall they are connected with the river. Thus, organisms when young may spend considerable parts of their life cycles in these ponds, traversing to the river during floods.

Sloughs and oxbows are also valuable feeding grounds for aquatic life. The oxbows are typically caused by the cutting of a more direct channel which naturally occurs when the meanders get very large. These areas which have slower flows through them are clearer, because the sediments have had a chance to settle out of solution. In these waters many more algae grow and it is here that fish come to feed. On these algae as one might expect, large populations of insects and other invertebrates may develop.

The sloughs, which are the mouths of former tributary streams, are also excellent feeding areas. In these reaches of the stream the effect of bankside shading is much less and the stream is dependent upon detritus brought in from the watershed and on primary productivity. The integrity of this system and its productivity are dependent upon the flood plains and these naturally occurring oxbows and sloughs. If they are eliminated, which sometimes happens in channelization, the productivity of this reach of the river is greatly curtailed.

Estuary: In the estuary the channel structure is very different from that of the rest of the river. Here we see the confined channel giving way to open marshlands. These marshlands function in a similar way as the wetlands in the upper reaches of the river. They are very productive; indeed Odum has characterized them as being the most productive areas in the world. They not only contribute algae or primary producers as a source of food, but the emergent plants, on their death in the fall of the year, create large amounts of detritus. A considerable amount enters the river system and furnishes food for many species of aquatic life.

The marshlands also function in improving water quality as plants and sediments assimilate large amounts of nitrogen, phosphorus, and other chemicals necessary for plant and microbial nutrition. The green plants also produce oxygen by the process of photosynthesis. Many plants may accumulate more nutrients than are necessary for growth. This luxury tends to be greatest in eutrophic water.

These plants also accumulate large amounts of substances such as heavy metals. The physiological mechanisms by which these large amounts of metals can be accumulated and not produce toxic effects are not well understood. However, recent research has shown that there are limits to this nontoxic accumulation of metals and when these thresholds are reached the metabolic rate of the algae is adversely affected.

In the open channel two-way flow is one of the characteristics of an estuary. This is due to tidal action. This effect may extend far upstream above the penetration of saltwater. Typically, in most estuaries the saltwater tongue which is more or less discrete, penetrates up the estuary along its bed, whereas freshwater flows occur over the surface.

The amount of freshwater flow depends on the discharge of the river. This is usually less in the summer, and the estuary will have a higher salt content than it will in the winter. Indeed, in some estuaries such as the Escambia, the saltwater tongue is so discrete that in the winter short-cycled insects may enter the estuary as eggs and go through their larval stages and emerge before the water becomes brackish in late spring or early summer.

Often there is a very different type of fauna and flora living in the winter in the surface waters than that which lives in the deeper waters where more brackish water remains throughout the year. Since there is considerable hold-up time in this part of the river, the estuarine communities in structure resemble more closely those of lakes, that is, one often finds plankton existing as well as benthic and epithetic forms.

In the free-flowing part of the river, the suspended organisms are really scuffed up bottom forms unless a dam is built into the river which introduces lake-like conditions. Exceptions to this are some of the long, slow-flowing rivers in the middle part of the country where plankton may develop. These plankton organisms are not true plankton as one finds in the open sea, because they do not spend their whole life afloat in the water. They typically have resting cells that lie on the bed of the river or lake.

Thus we see that the physical conditions of a river channel and the chemical and physical characteristics of the water differ in these various reaches. Likewise, the kinds of species composing the various communities differ.

However, there are great similarities among these communities, for their functions are quite similar. For example, in all of these communities there are detritivores (organisms that feed upon detritus), primary producers (organisms that fix carbon in the presence of sunlight and chlorophyll), herbivores (animals that feed upon plants), carnivores (animals that feed upon other animals), and omnivores (organisms that have a wide variety of diet).

Recent investigations have shown that it is extremely difficult to type a given species to a given function. The reason for this is that during the life span of a species, depending upon its stage of development, it may change its food preferences. For example, it may be a detritivore at one stage of its life history and an algae feeder at other stages. It is also well known that when a resource is limiting a species may switch to another food source. Thus, although a species may prefer to be a carnivore, when pushed it may become an omnivore.

These functions may assume varying importance in different types of aquatic ecosystems. In some systems detritivores may be more important than the primary producers. Likewise in some systems, omnivores are more prevalent than carnivores. Nevertheless, the same functions are carried out in all aquatic ecosystems that we have studied.

Furthermore, we find the numbers of species that perform these functions are very similar, in similar ecological habitats. Of course, when the physical and chemical characteristics of the habitats are very different, such as estuaries versus headwater streams, the numbers of species performing these functions may be different. However, in the same river area, when well-collected at different times, or in similar communities collected at the same time, the numbers of species performing these functions will be very similar.

This is in line with the work of Cody and MacArthur, who found that if one carefully equates the habitats, the numbers of species which one will find living in that type of habitat will be quite similar.

It is also important to note that the forces involved in the creating of aquatic ecosystems and the maintaining of them, seem to be similar. For example, the formation of a community is largely determined by the invasion rate, the size of the area, and the diversity of the area. The relative importance of these factors varies according to the species involved. Patrick, et al., in a study of diatom communities, has shown that invasion rate and species pool available to invade an area are more important than size of area.

However, with other groups of organisms, the diversity of habitat might be more important. The kinds and relative concentrations of various density-independent factors are very important in the maintenance of a diversified community. If these factors are variable and somewhat unpredictable, the relative population sizes of species will oscillate around a mean and the community will maintain itself over time. It is the opening of the community by these unpredictable occurrences that enables new species to invade and thus maintain a relatively high diversity.

Species interaction is also another factor determining diversity of an aquatic ecosystem. Bovbjerg has shown that if a single species of crayfish is present within a river it will occupy the riffles and slackwater areas and pools. However, if another species is introduced they will partition the environment with one being able to maintain itself in the riffles and the other one in the pool and slow slackwater areas.

Likewise, he has shown that physical aggression will exist between caddisflies in establishing areas for spinning nets. This has also been observed with the purse caddis on rocks. There is a definite spacing between the occurrence of these purse caddis, which is proportional to the area to which they can graze when they extend their thorax outside the purse case.

Species interaction which is not directly competitive but is accomplished by the excretion of various substances, is quite common among algae. In other words, a given species of algae may excrete a substance that will deter other algae from living within a zone close to the species. Thus, it can obtain nutrients in that area without much interference from other species. For example, Procter found that the growth of *Chlorella vulgaris* is greatly reduced in the presence of *Anacystis marina*. It is also reduced if the green flagellate *Chlamydomonas reinhardii* is present.

On the other hand, *Chlamydomonas reinhardii* is strongly affected and cannot grow in the presence of *Anacystis marina* and is greatly reduced in the presence of *Chlorella vulgaris*. *Scenedesmus quadricauda* is greatly influenced and its growth is retarded by the presence of *Anacystis marina*, *Chlorella vulgaris*, and *Chlamydomonas reinhardii*. The recent work of Keating (oral communication) also supports these conclusions.

Species may also affect the growth of other species by being able to utilize a given mix of nutrients. For example, it is known that *Asetrionella formosa* and *Fragilaria crotensis* grow best in cool water and effect the higher nutrient levels that are typically present in a lake in the spring of the year.

When these nutrients are reduced to a level that is not satisfactory for *Asetrionella formosa* and *Fragilaria crotensis* and the temperature of the water becomes warmer, *Synedra acus* will often become dominant. This dominant bloom is often followed by a bloom of *Dinobryon*. It is well known that *Melosira granulata* and many of the blue-green algae occur only in lakes where the nitrogen is very low.

Predator pressure is another factor that greatly influences the diversity of an aquatic community. If a predator has a preference for a species which is very common, the population of the prey will be greatly reduced and the community will be open for the invasion of other species. Paine has shown this to occur in the intertidal regions where the starfish preferred mussels. By reducing the populations of mussels, other species were able to invade and the diversity increased. Roop has shown that if predator pressure is against a given species the diversity of the community may be reduced. For example, she found that snails preying upon diatom communities discriminated against the ingestion of *Cocconeis placentula* and *Achnanthes lanceolata*. As a result, these species were allowed to grow and develop large populations and thus, the evenness of distribution of specimens among species was reduced and diversity was reduced.

Brooks and Dodson have also shown that the preference of a predator for a given size of prey may greatly change the structure of the plankton community. For example, they found that the introduction of fish that preferred a larger size *Daphnia* reduced the size of the population of this prey and allowed the development of smaller planktonic crustacea which, in turn, fed upon smaller algae. The relative size of the algal population increased while the size of the crustacean population decreased, as a result of the selective feeding by the fish.

Although all aquatic communities are shaped by the forces of these various factors, the relative force of a given factor may vary greatly. For example, in small ponds in the tops of volcanoes, fewer species are able to withstand the high concentrations of certain chemicals such as sodium and potassium and the lack of calcium which often exist in the volcanic lake. Therefore the numbers of species are greatly reduced.

Likewise, in the far north, with wide fluctuations in day length and lower temperatures, many species cannot live in this area and therefore the numbers of species available for invasion of the area are reduced. In such instances, the density-independent factor seems to be more important than predator pressure or competition in determining the structure of the community. In contrast, in a tropical forest competition and/or predator pressure may be much more important.

Perturbation of the natural conditions of streams may affect aquatic species in various ways. For example, perturbation may alter the physical habitat of the area in which the aquatic community occurs by simplifying the habitat or making it uninhabitable. In the channelization of streams the increased sediments fill the spaces between the rocks of the stream bed. As a result, the stream bed is homogenized, decreasing the numbers of physical habitats that previously existed. Likewise, the current becomes swifter and the current pattern is greatly reduced or homogenized due to the fact that the roughness of the river bed has been obliterated.

Other types of pollutants may make the river bed uninhabitable. For example, the accumulation of heavy metals in sediments may cause the sediment environment to become toxic to organisms that would ordinarily live in it. Another example is the accumulation of silt among the grains of sand which reduces the flow of water and hence, the ability of the organisms to obtain oxygen. As a result, many species which commonly live in large particulate matter such as burrowing mayflies, will not live if the interstitial spaces are filled with fine silt. These habitats are often the preferred habitats for the spawning of fish and the rearing of the very young larvae. These, too, will be eliminated if there is not a free flow of oxygenated water through the sediments.

Silt may also greatly reduce light penetration in water and thus make the bed of the river uninhabitable by algae. Since algae are often referred to as the grasses of the seas, the plant food source will be eliminated and the herbivores greatly decreased.

Pollutants may also directly affect reproduction and the physiological efficiency of organisms. An example of pollution directly affecting reproduction is that of small concentrations of dieldrin which will affect the behavior of fish and cause the male to fail to chase the female or stake out a territory.

Thus, very low concentrations which do not apparently affect the normal physiology of the adult under usual conditions, will affect the individual at breeding time and hence the reproductive process of the species will be diminished.

The effect on physiology has been found with large increases in temperature which may also be deleterious to organisms by causing the metabolic rate to be higher than the assimilative rate. Thus, the organism will not be able to obtain enough nutrition to survive. In other cases, it has been noted that shifts in temperature are necessary in order for insects to molt and in other cases, bass are known not to spawn unless the shift in temperature occurs from the low 60's to the high 60's in the spring of the year. The maintenance of too high temperatures may increase the incidence of disease.

The concentration of a given physical or chemical characteristic of the water may at one concentration be deleterious and at another concentration be advantageous. Therefore, the concentration of pollutants is a very important consideration in determining the effects upon an organism. For example, 1 or 2 degrees Farenheit rise in the winter has been found to stimulate oyster growth in the Patuxent River, and oysters which usually take 3 years to reach marketable size, have been known to reach marketable size in 2 years in slightly warm water. In such slightly warmed water, algae typically grow faster in the winter and the food for the oysters is also stimulated.

It has been found that extremely small amounts of certain chemicals such as manganese or vanadium stimulate diatom growth, whereas large concentrations may be toxic.

Response of communities to perturbation, particularly manmade pollution, is usually first evidenced by a shift in the sizes of populations of various species. Those species which are more sensitive to perturbation tend to have smaller populations; those that are more tolerant will increase in population size. Thus, a greater unevenness of the distribution of specimens among the species takes place and the diversity index is lowered.

More severe perturbation results in species substitution. For example, in a normally healthy stream one will find many species of mayflies and several species of stoneflies. If the oxygen in the stream is greatly reduced during certain seasons of the year, one will find a great reduction in the number of mayflies and stoneflies and in their place will be more species of chironomids, snails, and organisms that are tolerant of or prefer small amounts of organic pollution. Thus the species numbers will not be changed but the kinds of species will be greatly changed. If pollution is very severe, the numbers of species will greatly decrease.

We have found in algal communities over many years that the first effect of organic pollution is for a few species to become excessively common. The second or more severe effect is a shift of species from diatom-dominated to green algal-dominated, and if more severe, to blue-green algal-dominated communities. This shift is accompanied by a reduction in the species number but a great increase in biomass.

Toxic materials, on the other hand, have somewhat different effects. If the toxicant is one which does not kill the species but rather interferes with reproduction, one does not see a reduction in numbers of species but all species have very small populations. This is what happens when one lowers the pH of a circumneutral diatom community to about 5.5. If the toxicant is one that kills many species but allows the more tolerant to live, one then sees a greater abundance of these few tolerant species.

This has been found to occur with various heavy metals. For example, chromium will bring about a shift of a diatom-dominated community of many species to one dominated by *Stigeoclonium lubricum* and a few species of blue-green algae, with a large amount of biomass. Thus we see that not only are the numbers of species greatly reduced, but whether or not the populations or biomass are large or small, is dependent on the type of toxic material which is present.

Measuring the effects of pollution: Many people have sought to express the degree of pollution by various methods. The most common ones that have been used are histograms, dendograms, graphic models, or the development of the diversity index and plotting this against numbers of species.

Of these various methods, the developing of a model to express the aquatic community gives the most information because one can tell not only the numbers of species that are present, but estimate the numbers of species that are represented by different sized populations.

This is not possible by the use of a diversity index or dendogram. The histogram probably gives the greatest amount of information, but to date, this has not been put into a mathematical framework.

With a histogram, by heights of columns, one can indicate the numbers of species; by breadths of columns, the relative abundance of the species of a given group, and whether or not that group has species that are excessively large. One can also, by making the various columns represent various groups of species or single species, show something of species composition.

Comparisons of communities have been determined mathematically by comparing diversity indices, by clustering in dendograms, and by variance in model shape. Since the success of any aquatic community depends upon so many variables, it is very important that as many of these as possible be determined in defining stream condition. Therefore, it is best to examine as many different stages in the food web as possible as to the kinds of species and relative abundance of these species performing each function.

Similarly, it is important to look at the community as a whole as to its species diversity and kinds of species forming it. Finally, it is important to correlate this information with what can be obtained concerning the chemical and physical conditions of the water.

Because man is going to have to use the surface waterways if he is going to have a stable society, it is important that he not only diagnose the degree of pollution which is present and what is causing the pollution, but he also should find ways to prevent or greatly reduce the severity of the effects of pollution. For example, the discharge of a large volume of water through a single outlet into a river can greatly disturb the current pattern. However, if this water were discharged in a way to reinforce the natural pattern, far less severe effects would result.

Recent research by many workers has shown that trace metals may have a great deal to do with what species become dominant within an aquatic ecosystem. In other words, nitrogen, phosphorus, carbon, et cetera, are important in determining the number of organisms that a given body of water can support, but various mixtures of trace elements may determine what species are dominant. If these species have high predator pressure the productivity of the system will increase. On the other hand, if they form nuisance growths it will decrease. For this reason nutrient management of effluents may be an important way to improve streams rather than have them degraded by organic discharges.

Conclusions: From this study it is evident that natural aquatic ecosystems have a great deal of ability to cope with changing factors in the ecosystem. This ability to maintain a continuance over time is made possible by the large species pool with short generation time so that species performing a given function can change with given environmental changes.

There are also many feedback mechanisms so that organisms and subsequently nutrients can be recycled through the system. There are also present in performing each function, many different species representing many different major groups of organisms, orders, families, and genera. Their diversity in ecological requirements for growth provides the system with a greater flexibility than if a single group of species performed a given function.

The integrity of natural water systems is high. The important thing is that man learn how to manage the use of such waterways avoiding overburdening them so that the aquatic life in the streams is able to carry out natural cycling processes and assimilate wastes.

DISCUSSION

Chairman Guarraia: I think the point you raised concerning the diversity of populations bears out what many people have done in microbial systems to show the relationships, and I'm thinking specifically of some of the work that has been done by Dick Merita in Oregon in this line. It is certainly very exciting. Are there any comments?

Dr. Coutant: To carry on the debate a little bit in a bit of a different vein, one of the problems we seem to have is identifying what communities go with what combinations of physical and chemical characteristics.

I'd like your opinion on our ability to take a national census, if you will, of water quality data, physical and chemical primarily, that is being gathered now and has been gathered in the past and to couple that with usually completely unrelated ecological surveys to develop a list of species plus other things.

Do you think we could come to the point of being able to marry the physical and chemical data with the biological data and say, if you have this list of physical and chemical conditions, this is the kind of ecosystem structure you wind up with. Do you think we're near that? Do you think that would be a fruitful approach?

Dr. Patrick: I think to take completely different chemical and physical data from biological data and try to match them when they aren't collected at the same time is rather frivolous. It shouldn't be done.

We have done a great deal of work using the computer to monitor and we have found that if you take one chemical such as nitrate, and try to relate its concentration to a given species' flux in population size, in most cases you won't get it. But if you take a matrix of chemical and physical factors such as nitrates, phosphates, and certain trace metals, you can predict that you will have a diatom community. But we don't know how to do the matrix attempt completely yet, although we have had some success.

Dr. Coutant: This is really why I asked the question, too. I know you're having some good luck in matching things in individual experiments, you know, the two simultaneously, but again, being a little bit pragmatic in saying we don't have that ideal condition for most of our rivers and lakes and estuaries, but we do have a fairly good inventory in some places at least. Historical data have been gathered over the years, some of it well correlated and some of it not very well correlated. And you just have to hope that somebody will put all of this together somehow in some magical model and be able to know what goes with what. But that's a big job and I wondered if you had opinions on that.

Dr. Patrick: It's a terribly big job, and of course you know better than I that the methods of determining things differ so at different laboratories.

We've just published a study of the history of the Delaware River. By taking a number of chemical parameters and not trying to define the situation too carefully, we can see certain shifts like the migration of shad, and the shift in the productivity of the estuary, roughly correlated with BOD, oxygen, nitrogen, and phosphorus, but it's very rough.

I think it is just like asking a doctor to take a temperature one time, do a cardiogram at another time, and do other analyses at still different times—and then come back with the state of your health. That's pretty difficult.

Comment: I might add one thing. Under part of the law that we're talking about today, the 304-307 sections, EPA as a regulatory agency is going to require the industry or the manufacturers of materials to provide certain information on these materials to determine their environmental capability.

I think it was pointed out yesterday, this all ties into the integrity, and if we can tie this together with our mathematical models and get them to provide the information to go into the models and the impact on the various species and the functions of the ecosystems, then those materials that are being produced in the future will have this information.

And someplace along the line we're going to have to go back and screen some of it, the materials like toxic metals, the ones that are already in the environment, and find out how they fit into such a system and what their impact is. I think we are looking and working toward being able to bring all this information together about our aquatic ecosystems.

Comment: A number of people around the country have been trying to develop in one form or another a water quality index to be used for measuring, as we proceed into the future, whether or not all these wonderful things that we're doing for these millions of dollars are having any real effect on the quality of our waters. Most of the efforts that I'm acquainted with have been along the lines of utilizing the traditional chemical parameters of water quality or physical parameters, composited into some kind of an index.

More recently, I've heard some discussion of the possibility of using biological measurements for this purpose. Do you see any hope for this being a reality in the relatively near future, particularly for the purpose of communicating with the laymen, with the public at large? What our water quality problems are and what kind of progress we're making?

Dr. Patrick: We have already done this. We have model diatom communities, and in various papers that I have written we have determined how far we can continue without severely altering natural communities.

Typically, a normal curve is a model of a diatom community. Now, if an extension of a length of the curve occurs without reducing the height of the mode, and sigma square increases, you know that organic enrichment of the water has occurred.

By different shifts in the diatom structure—I won't go into them all now—we can tell roughly what kind of pollutant and what degree of pollution is happening in a given stream. We can measure very finely. Of course, anybody can go out and see if there are diatoms in the stream, and if there is a blue-green algal or *cladophora* bloom, and be able to say that the stream's polluted. You don't have to go to the more refined methods to determine gross pollution. But the importance of this method is that it tells you trends before they become severe, and I think that's the kind of monitoring that we must establish in this country.

We can't get all the answers before some pollution occurs, but we must set up a monitoring network that has meaning, and that we haven't done so far.

Comment: I'd like to add an additional comment to that. At the present time, the CEQ and EPA and USPHS are funding a study to look at the different types of indices that are available and see if we can come up with something that may be used in a national sense.

It's obvious from past experience, that this is not an easy thing to do. We are attempting to look at that now and also, in another sense, within EPA we're now conducting a study on environmental measurements. To take a look, not only at the water aspect, but at the air aspect. We're doing this at the request of the Administrator because of the different things that are coming to the forefront. For example, now we're doing major economic studies on the effects our regulations and standards are having on the economics of industry and the different types of things that they are doing. And also, requirements for the sewage treatment.

So, we're hoping to take a look at these things, and I myself am working on the study as are some of the other people here today. So we will definitely look at the potential for using biological indicators and we're looking at this in a context of a national system, and in a trend system.

Obviously, it's not an easy thing to do, because we also have to look at the pragmatic approach that Chuck talks about, with money and manpower. I know Dr. Patrick's system is a very fine system and I think one of the problems is that there are not too many people around who are able to look at diatoms and make predictions that you're able to make. Maybe you could respond to that.

Would there be enough expertise available so that we could use it as a predictive type model? For example, in our reports to Congress and to the public?

Dr. Patrick: I'd like to respond to that in two parts. One is that I think, for the general public, there's the attitude that one person in ecology can do everything. And I'd like to go back to my analogy of a doctor. Anybody can take your temperature, and if it's up to 104, you know you're sick. If it's only 100, you may not be quite sure that you're ill. You can be very ill, but the illness doesn't express itself.

What I'm trying to say is that just as in medical treatment, you get what you pay for. The more thorough and competent the examination, the better the diagnosis. The more you try to reduce things to a single number, the more you lose in the measurement.

The important thing is to know the spectrum and the questions. To answer you, if you want to roughly know whether a body of water is going downhill, take a few measurements; it's just like taking your temperature. You could do a diversity index; anybody could do that, you don't have to know species, only recognize differences. And you can make a diversity index which can roughly say, this is different from that.

But, if you want to know if one or another kind of pollution is present, you have to do other things.

Maybe you have to analyze it to see if it's radioactive, if you're interested in radioactivity. Algae rapidly accumulates radioactivity. Or you may have to do studies on heavy metal content, or look more closely at the community structure.

I think it depends on the degree of information, its accuracy and completeness that you want.

As for diatom people, we could easily train people, in fact we're training a lot of them in about a year to do this kind of work. And we have other kinds of measures which are quite good, not as good as the model, but what we sometimes call a semi-detailed reading of a community which is done very quickly, in a few hours.

So, I think, again, it all depends, and I don't think you ought to try to come up with any one way. In other words, you ought to have different degrees of information, just as we do for medical examinations, depending on your questions.

BIOLOGICAL INTEGRITY—A QUANTITATIVE DETERMINATION

FISHERIES

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I first read the provisions of the Act pertaining to restoring and maintaining the biological integrity of waters immediately after reading about the bluefin tuna situation in the North and South Atlantic Ocean. The report by Frank Mather of Woods Hole Oceanographic Institution, published in the bulletin of the International Game Fish Association in 1974, tells about the imminent collapse of the bluefin tuna fishery that has been a staple commercial fish, both in the Atlantic and the Mediterranean, since before the time of Christ.

As recently as the 1960's the catches of this species made by the Portuguese, Spanish, Moroccan, Norwegian, German, and American fishermen were in the 10,000 to 20,000 range per catch. But in 1972 and 1973, some nets took only one or two fish, and some companies or fishing organizations took only 1,500 or so fish in a whole year's time.

One catch of 111 fish averaged 1,040 pounds per fish, which should make some fishermen in the audience open their eyes a little bit this early in the morning. But the total weight of that one catch was only 55 tons, whereas the same people with the same nets earlier had been taking 150,000 such fish in their catches.

Obviously, that fishery is in a state of collapse and it is probably due to over-fishing. There are three reasons for thinking so. But, here is a biological integrity problem that fits Webster's definition. I immediately began to wonder, "Will the EPA Administrator develop and publish information on the over-fishing factor which is just as important, in many respects, as some of the other factors he has to think about?"

Along about that same time, I heard Dr. Betty Willard of the Council on Environmental Quality speak before the American Society of Civil Engineers in Montreal. In essence, I think I heard her say that a lack of integrity may mean an imbalance among the chemical, physical, and biological elements of an ecosystem that threatens the vitality and productivity of some, or all, species of the system. It may mean a disruption of the biological system to the point where it can't support the organisms within it any longer. She said, too, that many generations may be required to restore the productivity and complexity and stability of this system.

Well, the words "imbalance" and "disruption" and "stability" held me up for awhile because, to me, the biological world is full of imbalances and disruptions and instabilities. It is constantly altering its makeup, its inputs, its outputs, its proportions, its internal relationships, in response to a host of outside and inside factors.

Many of these factors are not manmade in any way. So, what are we thinking about in talking about integrity? A changeable situation, apparently. Are we really trying, in response to a legal directive, to stop the world and freeze its action like a one-shot frame in a motion picture? Or are we trying to hold a picture, or situation, forever static in accord with what we think the world ought to be like? I sometimes think we are, and I sometimes think that's not the way to do it. At least, we can't achieve our goals very well if we have that in mind.

If we're to talk about the factors necessary to restore and maintain fisheries, we have to have some goals to work toward, some idea of what we want to achieve. What fishery levels, for example, to restore or to maintain.

There's much information available now, on both the total tonnage of fish present in the lakes and streams of the United States and the yield from those fish populations each year. Isaac Walton knew very well that he was catching his biggest fish in the streams that drained the richest valleys in his country. Now we can document that with all kinds of facts and figures. We can discuss the waters of New Brunswick that flow over rather insoluble rocks and have very few nutrients in them. They contain a total fish population of anywhere from 17 to 36 pounds per acre.

The waters of northern Michigan, as reported in the literature, drain from very porous and sterile sandy soil and have about 38 pounds of fish per acre. In contrast, the average of many Minnesota lakes, in more fertile soil surroundings, reaches 150 pounds per acre, and in central Illinois, the figures are around the 600 pound per acre total weight of fish. Fertile land produces fertile water and fertile water, of course, would produce the greater total food chain and more fish.

The same is true in our estuaries around the fringe of our continent and it's true in the ocean waters where upwellings of fertile water from some of the depths are conducive to greater plankton production. That's where the biggest fish tonnages are harvested too.

The amount of life in the water depends not only upon the dissolved nutrients, but in addition, the rate of fish production is also governed by water temperature and sunlight. A lake in northern Wisconsin, for example, can give up as much as 20 percent of its carrying capacity of fish in 1 year's time without reducing the total poundage of fish in the lake. A lake in southern Louisiana can produce 118 percent of its carrying capacity in 1 year's time. It recycles things faster.

These carrying capacities are not firm and fixed and yields aren't either, of course. They vary from year to year in adjustment to many factors. The winterkill situation in the lake states offers an example. When winter snows cover the ice and shut out sunlight and prevent oxygen production, eventually the decomposition of the bottom robs the shallow lake's volume of all of the oxygen. That may drastically reduce the fish population in those lakes and, of course, reduce the yields too, either to the commercial fishermen or to the angler. But the survivor fishes, and there generally are survivor fishes of a few species, make remarkable increases in growth rates and they get that lake back up to its productive limit very quickly.

The productive capacity varies in regard to another factor, too. Lake Senachwine in Illinois varies from 3,000 acres one year to 6,000 acres the next because of the water level fluctuation. But its carrying capacity remains between 50 and 55 pounds per acre, no matter what the size of the lake is. That is the conclusion of the Illinois Natural History Survey a few years back. The total tonnage of fish goes up and down with the total acreage, but the carrying capacity per acre remains about the same.

There are other quantitative manifestations that bear mention. A prairie lake under fairly fertile conditions may contain, if it is managed in one way, 200 to 300 pounds per acre of game fish species. Or, if the lake has a mixture of game fish and rough fish species, the total poundage per acre would be closer to 600 pounds. If it had rough fish only, like carp and buffalo fish, the total poundage would probably be closer to 1,000 pounds per acre.

The latter fish, the carp and the buffalo, utilize the nutrients in the water on the bottom much more directly. The game fish, at the peak of the food chain, produce fewer pounds at that peak. If we are to think in terms of integrity and have goals to reach, which goal do we want to reach? A given set of conditions produces not only a given number or weight of individuals in a lake, but also determines what species are in that lake.

Pristine waters of large size are usually low in nutrients. They are clear and cool and they will have lake trout and whitefish, perhaps only 1 or 2 pounds per acre. Lakes with greater nitrogen fraction amounts and phosphorus compounds plus carbonates, sulphates, chlorides, and many minerals, will have a bass or bluegill type population, or a walleye and perch grouping, or a bullhead and green sunfish grouping. Carp can't survive well in a lake trout lake and lake trout wouldn't live in a carp lake. The quality of the water determines what species will be there, too.

Bringing man into the picture adds another whole set of factors. The natural ponds in Alabama, on the whole, produce 100 to 200 pounds of fish per acre per year. When the disciples and descendants of Dr. Swingle stepped in, the fertilized ponds in Alabama began to produce 500 to 600 pounds of fish per acre per year.

Putting a dam across the Green River in Wyoming and Utah to produce Flaming Gorge, or across the Colorado River to create Lake Powell, eliminated many miles of stream habitat for native river fishes. Of course, that was regretted and objected to, but those dams afforded water for development of excellent rainbow trout fisheries and largemouthed bass fishing. Now, who is to judge the comparative values in the two sets of conditions? Which integrity do we want to hold?

There's another question that comes to mind: how far do we expect to go in the restoration effort? During many years as Federal Commissioner on the Ohio River Valley Water Sanitation Commission, I was always fascinated by the descriptions of the Ohio River and the valley, in Rafinesque's day, in the early 1800's. I look out of my car window, or tow boat window, or my hotel room window, about 175 years later and see what the Ohio River looks like now. The wording of the Act and the intent of the hearings give us the obligation of restoring that river to its former condition.

In literature, you can find references to the terrified reactions of Marquette and Joliet as they were coming down the Mississippi River in 1673 and suddenly came to the point where the Missouri enters. They were faced with a flood of enormous proportions coming in from the Missouri River. They had never seen anything like it. The Missouri's swift current and siltiness fascinated Lewis and Clark in 1804-06. There was an integrity to that river; it had its own fish population; it had a balance within limits, a range of conditions. Some of the early human residents on the upper part of the river used the fish. Is that the kind of integrity we're supposed to restore? Should we knock out those six dams on the upper part of the Missouri and go back to the way things were?

I think that guidelines have to be worked out and I'm groping for some. In my vague way, I'm really searching for some bench marks that we must have to guide us in restoring and maintaining what is called the biological integrity of waters, keeping the fish populations in mind.

In nature the balance, or integrity, is a changing thing. What manifestations of the balance do we choose to be our objectives and goals? That same Missouri River was so loaded naturally with phosphates that I recall Dr. Tarzwell, back about 1949, fearing that when the dams went in and the current was stilled and the silt was dropped, and the waters cleared, and the sunlight began to do its work, we would have the most "blooming" river anywhere on the continent. It was a possibility; it didn't happen.

The droughts of the middle 1930's through the prairie country eliminated whole lakes and stream systems and their fish, too. The lake beds were sometimes farmed. When the rains returned, the productivity of those lakes and streams was unimpaired. It might have even been enhanced.

We wouldn't like to have a norm involving such fluctuations, but they have to be considered. Going far back into history, the changes in climate have forced a retreat of several species of fish, hundreds of miles from where they once were, back to the northeast, where they now live. Even before, in early Pleistocene times, the advance of the ice sheets forced brook trout down into southern parts of the United States, into southern Missouri and Arkansas. Do we keep these things in mind in talking about natural characteristics or integrity of our fish population?

In more recent times I recall that the forest fires in northern Wisconsin released nutrients from those burned watersheds into the headwater streams of the northern part of that State and apparently had a hand in fostering the development of tremendous stands of wild rice, or at least coincided with the stands of wild rice.

But the growing up of watersheds, under tight fire protection, now has coincided with the demonstrated impoverishment of those waters, and a complete disappearance of wild rice. Which degree of integrity do we want here; which condition do we want to restore?

I'd feel better if an administrative conclusion were reached that it is the influence of man we're talking about. Our goal is to nourish our waters and watersheds and their water inhabitants back as closely to the pattern of variable conditions that existed before man's influences became so paramount. Despite the vagaries and shifts of these natural conditions, they did produce resilient and diversified animal and plant communities. These diversified communities accepted the whole spectrum of change as a natural thing; they lost a few individuals and, occasionally, a few species. In other times and certain situations, maybe more individuals were gained and species were added. A permanent and unchanging period probably never existed, and a stable, maximum fish production, or fish population, probably never existed either.

There was a pattern of factors that held true over long periods of time, and this pattern we should keep, seek to restore. Determining these factors and ranges has been a big research task. We're not finished with it; the details are not worked out well. A lot will be done in the next 7 to 10 years by private organizations, academic institutions, Federal and State agencies, to work out the details that we're seeking right now to answer some of these integrity questions.

There is a point that I would like to make. It is agreed by fisheries professionals that many of the factors bearing on the welfare of fish populations are applied at some distance from those fish populations, or from the waters in which they live. I think you all know this, but I noticed you had an acquaintance here who talked about channelization.

Agricultural practices on a watershed affect the quality of water draining from that watershed and also affect the fish in that water. That is elementary. I think we can remember that wastes flowing into the Mississippi River at Memphis a few years ago affected the welfare of one species of fish 800 miles downstream. Very clearly and not unexpectedly, the effect on the fish population appeared where the stress was applied, at the mouth of the Mississippi.

I'm wondering if the record of growing acidity in New England lakes, particularly in Maine and New Hampshire, might not be related to the change in fuels now being burned in Pittsburgh. The jet streams could be a transportation agent from source to effect.

Also, some of the factors that have a bearing on water integrity and on our fish aren't visible at all. A fish population doesn't have to be killed outright, it doesn't have to give evidence of immediate death and float downstream or ashore, to be exterminated. The fish population can be stopped in its reproductive efforts or in its ability to convert from fresh water to saltwater, as in the case of salmon, and therefore, die out just as surely as if it were killed immediately from some acute factors in the environment. The factors producing chronic effects are just as important as those that produce the immediate, visible, acute effects. They are much less spectacular and a lot harder to work out.

I would like to mention one development that I was quite interested in while I was working with the National Science Foundation. The University of Texas Marine Science Institute at Port Aransas has created and tested a method for assessing the effects of natural and manmade changes on the estuarine environment and it has applied that method to the Corpus Christi area. The State government is using this method and several other related methods to evaluate changes and to manage the development of Corpus Christi's coastal area.

The Marine Science Institute has established three data banks: one on the distribution of hydrographic features and the nutrients and other material contained in the water or in the sediments; another on the life history, the food preferences, and the environmental limitations of the estuarine organism; and a third on the commercial and sport fishing catch and effort in that area.

The total catch of fish in the gulf for 1973 was about 1½ billion pounds. Of that total, 485 million, or 30 percent, was sport fish catch. These fish, this tonnage, came off the continental shelf and inshore coastal areas. This gives a good indication of the coastal fertility and productivity of those waters.

By measuring the dynamics of Corpus Christi Bay and providing information on how man's changes in those areas, through shoreline development or waste discharges, are affecting those biotopes, the investigators and the regulators are getting a good idea of how the changes are affecting the productivity of their whole system. They now know which factors are the ones that have to be watched.

This has been a very general discourse. As I come to the end of my thoughts on this subject, I think about developing an action program once we have determined our goals. We may not have our objectives quite clearly in mind yet. Our course of action certainly won't be direct. I do think professional decisions are not all that hard to reach today and that we ought to make a few of them and let the legislators and the water users and citizens know what the professionals think, then let the political and economic and social processes begin to respond.

DISCUSSION

Comment: I've spent my life in this business. I've been grappling with this business of integrity and what we want or don't want. So, this morning before the meeting I took a shot at writing the definition and I'd like to ask Mr. Johnson what he thinks of it. Here it goes in its rough form:

Water may be said to have integrity when it directly serves the needs of man and indirectly serves the needs of man by serving the needs of plants and animals that are important to man, by enhancing man's food and preserving a good and healthy environment in which man can live well over thousands of years.

In other words, water being inert has no integrity as we think of humans having integrity; it has a function. I think that man has risen to a point on this earth because he had brains and could think and other things couldn't. I think it's not too self-centered for man to make use of what is available for his own benefit.

Mr. Johnson: I certainly appreciate hearing that; it covers the waterfront and many water uses. I don't have any profound comment to make.

Chairman Frey: I think that one of the very important things that Ray brought out is that we can't think of a status quo without thinking of the inherent changeability that's in the system anyhow. So whatever definition or principles are adopted as guidelines they're going to have to take cognizance of this natural changeability that is in the system in response to naturally occurring stresses outside.

I also personally feel that his emphasis on the additional changes imposed by man's activities stresses the ones that we are going to have to zero in on and, quite possibly, the ones that are inherent in the intent of the law. Maybe someone would care to raise opposition to that and engage Ray and me in combat.

Comment: I would, sir. In major engineering works, whether they're for Federal, State, local, or private purposes, we are imposing now (or are confronted with, depending on which side of the table you sit in the planning process) a requirement for an environmental impact statement or environmental assessment; one of the requirements in this matrix is to show that there's no degradation, or, if there is to be degradation, that it is quantifiable, and further, to show that other alternatives were considered.

This proposal that you are making offers the least. Now, if we as professionals are unable to quantify or to set a time frame, how can a major development such as the Cleveland Airport expansion, or the Transit Authority, or the Alaskan Pipeline do this? How can this cost be levied on a reasonable, equitable, cost sharing basis?

Is it the man who comes first and says, "This piece of ground is to be converted from a natural state for my purposes, therefore, I bear the cost." Or, are the people who come later to share to be charged a user charge, or, in the case of private industry, do we demand that all of the money be put on the table and say, "You want it, you pay"? How can this be done?

Mr. Johnson: In many ways under many different conditions, I presume. I was part of the Alaskan Pipeline effort, and I hate to think of the number of hours that several of us spent on that environmental impact statement on behalf of the Department of the Interior. In looking back on that one particular effort, I'm glad there was a delay because the engineering wasn't right in all respects. Corrections in design have now been made.

On your cost question, I don't have a good answer, but this kind of question is usually answered by three different types of inputs, finally somehow reaching some kind of a tripod agreement: the biological and natural history input, the economic and social input, and the political and administrative input. Those three will have to get together and shape the decision on any one of these problems that you have raised. They may be different decisions in each case, but the process may remain about the same.

QUANTIFICATION OF BIOLOGICAL INTEGRITY

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Biological integrity may be defined as the maintenance of the community structure and function characteristic of a particular locale or deemed satisfactory to society. In this regard, two points deserve particular emphasis. First, the assumption is made that all natural systems are dynamic and as a result are characterized by a continual succession of species, although the rate of succession may be quite different in different systems. Thus, the protection of a particular species, however valuable from a monetary or other value system, may be counterproductive because it attempts to "freeze" a dynamic system. The conflict between the protection of systems and the protection of species is discussed at length in Cairns (1975).

Second, standards based on this definition of biological integrity will be highly site specific. Therefore, while the criteria (namely maintenance of normal structure and function) will be the same throughout the United States, thus maintaining the equality before the law philosophy, the standards for each particular locale, even within a single state, may be different. This merely recognizes something that the Department of Agriculture has recognized since its inception, i.e., ecological conditions are not the same throughout the United States and attempts to ignore unique regional ecological conditions are stupid and doomed to failure. This would hardly be worth saying were it not for the fact that environmental legislation continues to ignore regional differences probably because of fear of the complexity of the legislation which takes these into consideration. However, it is almost certain that environmental quality control will be unsuccessful until regional differences are acknowledged.

STRUCTURAL INTEGRITY

It is not my intention to attempt to discuss at length the literature showing that natural communities have certain structural characteristics which may be depicted numerically. However, we are all deeply indebted to such early investigators as Preston (1948), Patrick (1949), and others. Also worthy of note is the equilibrium model of MacArthur and Wilson (1963) which showed how community structure could be maintained despite the successional process. In addition to the scientific justification for the use of structural integrity as a means of assessing pollutional changes, there is also substantial benefit in communicability of results, since numbers are more easily understood by nonbiologists than an array of Latin names.

Only three basic kinds of information are presently useful in the quantification of the structural aspects of biological integrity. These are (1) the number of species or other taxonomic units present, (2) the number of individuals per species, and (3) the kinds of species present. Within this framework are such things as spatial relationships, density relationships, and various trophic relationships.

INDICATOR SPECIES

Biologists have long recognized that certain species tend to be found in certain habitats and, therefore, the presence of a certain species indicates that certain ecological conditions exist and the absence of the species that these conditions do not (assuming the species are able to get there). This is, of course, an oversimplification but space does not permit a more detailed discussion. It was probably inevitable that there would be an attempt to transfer this reasoning to the assessment of pollution by stating that certain species are found where polluted conditions exist, others where conditions are semi-polluted, and still another group of species where healthy conditions exist. Unfortunately, pollution covers a much broader range of conditions than most habitats for which biologists predict with reasonable certainty that certain species will be present.

One of the principal faults with the indicator species concept is that a species may be very sensitive to thermal discharges but rather tolerant of a particular chemical toxicant or high concentration of suspended solids, yet all are forms of pollution. A more extended discussion of these weaknesses in the indicator species concept may be found in Cairns (1974a).

However, if one has faith in the indicator species concept, one may collect the species from a particular habitat or locale exposed to a presumed pollutant and determine the number of species in each of the various saprobic categories and either compare these to a reference area not exposed to the source of pollution or some other reference aggregation of organisms. Using this approach, it is possible to get a quantitative comparison of one area with another area. Proponents of the saprobic system have provided increasingly sophisticated analyses of the tolerance of various types of organisms.

Although I do not believe that sufficient information now exists for most areas of the world to make the saprobic system functional, it does seem possible that eventually a sufficiently large information base will revitalize this assessment method. This information base should include detailed information about the tolerance of each species as well as a sufficiently large list of species to insure that an appreciable number will be found in each and every locale where assessments of biological integrity might be made. Until the information base is broader than it is now, the saprobic system does not have general applicability. Since one probably will not know precisely what species are in a particular area until they are collected, much valuable time would be lost if, after collection and identification were completed, one found no saprobic designation for most of the species collected.

THE PATRICK HISTOGRAMS

The histograms developed on the Conestoga survey by Ruth Patrick (1949) and her colleagues at the Philadelphia Academy of Natural Sciences represented a major breakthrough in the quantification of the structural aspects of biological integrity. The principal advantages of this method were: (1) it displayed the number of species in each of seven major categories graphically; (2) it provided a crude means of distinguishing between "normal" abundance and "over" abundance; (3) it permitted detection of gross pollutional effects; and (4) its effectiveness was not markedly reduced by successional changes or small differences in habitat, which would be important if one were using species lists alone.

The principal weaknesses of this method were: (1) a highly trained team of specialists in different taxonomic disciplines was required and thus the method was difficult to use on a broad scale because of the lack of skilled specialists; (2) it only provided four major categories of "health" and very often the presence or absence of a few species might alter the designation from one category to another (this, of course, could be offset by an extended discussion which would complicate the communication problem); (3) the time required to obtain the information often extended to months because of the difficulty of identifying certain species (of course, in an emergency situation this could be substantially shortened, but nevertheless, the identification process requires at least several weeks). One should remember that this method was developed over 26 years ago and it should be judged in the context of its time—at that time it represented a major turning point in the quantification of biological integrity.

A number of methods followed which attempted to reduce the number of the specialists required and the complexity of the Patrick histograms and retain the basic analytical thrust. Examples of these are the methods of Beck (1954, 1955) and Wurtz (1955). These latter methods combined elements of the saprobic system with the Patrick method and concentrated on a relatively narrow spectrum of the aquatic community in order to simplify identification and analytical problems. It is probably fair to say that they represented a variation on already established themes and not a conceptual advance. The work of Gaufin and Tarzwell (1952) and Gaufin (1956) on Lytle Creek, based on the same assumptions as Patrick's, represented a major contribution in the quantification of biological integrity since it showed the quantitative and qualitative structural changes that occurred when an aquatic community had been severely stressed by pollution and underwent a recovery process.

BEAK METHOD

The method developed by Beak, et al. (1959) was primarily for lakes but might well work in certain streams where there are one or two species persisting for a substantial period of time in substantial numbers. Essentially the method consisted of determining the density of one or more established species in two concentric rings at different distances from the waste outfall. Changes in proportional abundance in these two rings indicated pollution since presumably there would be a concentration gradient proceeding away from the outfall in much the same manner that ripples expand as they leave the spot where a thrown stone enters pond water.

There are several advantages to this method: (1) one does not need a substantial amount of taxonomic expertise because only a few species are involved; (2) the results are expressed on a graded scale; and (3) the method provides for determining with 95 to 99 percent confidence whether or not a significant change occurred.

Among the disadvantages are: (1) the chance that the organism or organisms one has selected may be highly resistant to the particular stress being assessed; (2) the "noise factor" in density assessments is often quite high; (3) one's test species may be wiped out by some natural catastrophe and leave one without any way of determining whether or not pollutional stress has occurred.

PATRICK DIATOMETER

The diatometer developed by Ruth Patrick, Matthew Hohn, and John Wallace (1954) represented a substantial advance in the quantification of the structural component of biological integrity because with the use of an artificial substrate, it substantially reduced the "noise factor" due to habitat differences and time of substrate exposure. In addition, it used a more sophisticated method based on a log-normal distribution of species abundance developed by Preston (1948).

Preston (1948) showed that for a sufficiently large aggregation of individuals of many species, the species-abundance relationship often conformed to a normal law, after the individuals were grouped on a logarithmic scale. That is, the observed distribution could be graduated by

$$y = y_o \exp - (aR)^2 \qquad (1)$$

where y represents the number of species falling in the Rth "octave" to the left or right of the mode, y_o is the number of species in the modal octave, and "a" is a constant that is related to the logarithmic standard deviation, σ, by

$$a^2 = 1/2\sigma^2 \qquad (2)$$

Preston's original method involved grouping the individuals into octaves with end points r = 1, 2, 4, 8 . . . These end points were subsequently labeled 1 through R, the total number of octaves. Those species that fell on a group end point were split equally between that octave and the next higher or lower octave. If an entire log-normal population is censused the curve extends infinitely far to the left and right of the mode and is symmetrical. As Preston (1962) pointed out, however, species are not found infinitely far from the mode in either direction and he describes an intuitively reasonable method of determining the end of the real finite distribution of individuals and species.

Given then, a complete ensemble or universe, the nature of the distribution can be ascertained. However, it is exceptional in ecological work that a complete universe, or "population," or "community," et cetera is fully censused and in most instances one must be content to deal with samples from a universe (Preston, 1962). Provided that a sufficiently large random sample can be drawn from the universe, the distribution will be truncated on the left, indicating that there are additional, uncensused species in the ensemble, although they may comprise only a relatively small percent of the total. To census these species (i.e., to obtain the universe) would require extraordinarily large collections which, for practical purposes, would be out of the question. However, provided that the sample is large enough to ascertain the mode of the distribution, both y_o and σ can be determined and thus, the extent of the complete, untruncated log-normal distribution (i.e., the number of species in the universe). Deducing the universe from a random sample is carried out by means of internal evidence at hand and not by an external assumption; the universe we deduce is based on the nature of our sample (Preston, 1962).

Species-abundance relationships are based upon two fundamental types of data: the number of species in the community or universe and the relative proportions of individuals among the species. For purposes of quantifying these relationships it is advantageous for the ecologist to be able to summarize his data in one or two descriptive "community statistics." When the data conform to the log-normal distribution, the obvious descriptors would be the logarithmic variance, σ^2, and N, the number of species in the biological universe. Other suitable parameters are a, a measure of dispersion, and y_o, the height of the mode. The important point is, however, that the species-abundance relationship can be adequately summarized by one or two general parameters which facilitates quantitative comparison of two or more communities.

A number of difficulties arise if the log-normal distribution is relied upon as the underlying theoretical relationship of species abundance. First, it has not been shown to be sufficiently widely applicable to all types of biological ensembles, to date. Preston (1962) cites numerous cases where the log-normal is adequate and Patrick, et al. (1954) have used this distribution to describe the occurrence of diatom species in fresh and brackish water environments. However, these are limited applications of the theory and do not confirm its ecological universality. Biological ensembles of relatively small extent usually require other methods of quantification since their distribution cannot be graphed with much success.

Secondly, a large amount of data must be collected and censused, even for the truncated form, so that the mode of the distribution can be exposed. In some situations, this fact alone prohibits the use of the log-normal distribution. Thirdly, the estimation of the parameters of the distribution, i.e., the mean and standard deviation, is difficult although computer programs for this purpose are available (Stauffer and Slocomb, manuscript in prep.).

These are the primary reasons that ecologists have turned away from this type of species-abundance quantification in favor of methods that do not depend upon the theoretical form of distribution of individuals among species. Indices based on information theory, although more difficult to visualize biologically, have gained great popularity as descriptive measures of community structure. Despite its drawbacks the diatometer method is one of the soundest available for the quantification of biological integrity. The aquatic ecology group at Virginia Tech has a substantial program designed to reduce some of these problems (Cairns, et al. 1974; Stauffer and Slocomb, manuscript in prep.). This indicates our belief that the method is basically sound and will continue to provide valuable information about biological integrity.

DIVERSITY INDICES

The diversity index is probably the best single means of assessing biological integrity in freshwater streams and rivers. It is less effective and may even be inappropriate in lakes and oceans. As a screening method for locating trouble spots in most flowing systems, it is superb! Unfortunately, many investigators looking for a single all-purpose method, use it alone when an array of evidence is required. Beware of the investigator who tries to use a single line of evidence of any type instead of multiple lines of evidence to assess biological integrity. A brief discussion of diversity indices follows.

Diversity indices that permit the summarization of large amounts of information about the numbers and kinds of organisms have begun to replace the long descriptive lists common to early pollution survey work. These diversity indices result in a numerical expression that can be used to make comparisons between communities or organisms. Some of these have been developed to express the relationships of numbers of species in various communities and overlap of species between communities.

The Jaccard Index (1908) is one of the most commonly used to express species "overlap." Other indices such as the Shannon-Weiner function (Shannon and Weaver, 1963) have been used to express the evenness of distribution of individuals in species composing a community. The diversity index increases as evenness increases (Margalef, 1958; Hairston, 1959; MacArthur and MacArthur, 1961; and MacArthur, 1964). Various methods have been developed for comparing the diversity of communities and for determining the relationship of the actual diversity to the maximum or minimum diversity that might occur within a given number of species. Methods have been thoroughly discussed by Lloyd and Ghelardi (1964); Patten (1962); MacArthur (1965); Pielou (1966, 1969); McIntosh (1967); Mathis (1965); Wilhm (1965) and Wilhm and Dorris (1968) as to what indices are appropriate for what kinds of samples. An index for diversity of community structure also has been developed by Cairns, et al. (1968) and Cairns and Dickson (1971) based on a modification of the sign test and theory of runs of Dixon and Massey (1951).

Diversity indices derived from information theory were first used by Margalef (1958) to analyze natural communities. This technique equates diversity with information. Maximum diversity, and thus maximum information, exists in a community of organisms when each individual belongs to a different species. Minimum diversity (or high redundancy) exists when all individuals belong to the same species. Thus, mathematical expressions can be used for diversity and redundancy that describe community structure.

As pointed out by Wilhm and Dorris (1968) and Patrick, et al. (1954), natural biotic communities typically are characterized by the presence of a few species with many individuals and many species with a few individuals. An unfavorable limiting factor such as pollution results in detectable changes in community structure. As it relates to information theory, more information (diversity) is contained in a natural community than in a polluted community. A polluted system is simplified and those species that survive encounter less competition and therefore may increase in numbers. Redundancy in this case is high, because the probability that an individual belongs to a species previously recognized is increased and the amount of information per individual is reduced.

The relative value of using indices or models to interpret data depends upon the information sought. To see the relative distribution of population sizes among species, a model is often more illuminating than an index. To determine information for a number of different kinds of communities, diversity indices are more appropriate. Many indices overemphasize the dominance of one or a few species and thus it is often difficult to determine, as in the use of the Shannon-Weiner information theory, the difference between a community composed of one or two dominants and a few rare species, or one composed of one or two dominants and one or two rare species. Under such conditions, an index such as that discussed by Fisher, Corbet and Williams (1943) is more appropriate.

FUNCTIONAL INTEGRITY

Only a limited effort has been made to assess the impact of pollutional stress on the functioning of aquatic communities. Nevertheless, it has become increasingly evident that approaches and methods to evaluate the effects of stress on the functioning of aquatic communities are badly needed. Functional characteristics of aquatic ecosystems such as production, respiration, energy flow, degradation, nutrient cycling, invasion rates, et cetera are related to the activities of various components of the aquatic community. The importance of these activities is obvious yet the availability of methods of studying these activities is miniscule.

The importance of being able to evaluate the effects of pollutants on both the structure and function of aquatic communities has been recognized by the Institute of Ecology's Advisory Group to the National Commission on Environmental Quality which has identified biological integrity as the pivotal issue in the assessment of pollution effects. Their definition of biological integrity (which this author helped prepare) emphasizes both the structural and functional aspects of natural ecosystems and communities. In addition, The Federal Water Pollution Control Act Amendments (PL 92-500, Sec. 304) states water quality criteria should reflect the latest scientific knowledge on the effect of pollutants on biological community diversity, productivity, and stability, including information on the factors affecting rates of eutrophication and rates of organic and inorganic sedimentation for various types of receiving water.

In general, assessing the impact of pollution on aquatic systems has been troublesome. Community structure analysis has been preferred to investigations of function in dealing with perturbation of aquatic systems because its study is less time consuming, better understood, requires less effort, and has become conventional. Community function has been avoided because methods dealing with its complex operation have been lacking. Furthermore, field studies have been hindered by fluctuating environmental quality plus the fact that the dynamics of systems are inherently more difficult to measure than the components themselves. Clearly, there is a need for the study of aquatic community structure. However, such studies provide incomplete information. Function must be coupled with community structure investigations to obtain a full understanding of the effects of pollution relative to the health of aquatic communities.

Structural analyses in the form of species diversity, species lists, and numbers of organisms have not adequately filled the regulatory agency's need for information on the response of aquatic communities to pollutional stress. Diversity indices place values not on organisms which may be present in small numbers but on those which perform vital functions in the maintenance of community integrity. The symptoms of pollution may be masked by shifts in the dominance of some community members without substantially altering the diversity. It is also difficult to establish whether these shifts or changes are beneficial, detrimental, or indifferent. Because identical assemblages of organisms never reoccur in natural systems, there is no "true natural fauna" which remains constant through time. The high functional redundancy of communities makes it possible to lose one or several pollution-sensitive species and still maintain adequate function. Species lists and numbers give little information other than what is present in an aquatic community at any point in time.

Function, however, provides better insight into the interaction of populations, the cycling of energy, and nutrient exchange in a community. Ideally, any studies of communities affected by pollution should include both structural and functional assessment, as well as the possible interrelationships between the two components.

Although there is no body of quantitative methods for the assessment of the functional integrity of biological systems there are a number of possibilities. A few examples of these follow (if I have left out your favorite method, don't write to me, use your energy to perfect its application in the determination of functional integrity).

PROTOZOAN INVASION RATES

It is possible that a determination of the invasion rate of a protozoan-free substrate placed in a freshwater lake or stream may alone be sufficient to estimate the degree of eutrophication; if this is the case, a rather easily carried out assessment requiring only a few days will be available. It is also highly probable, however, that additional useful information will be gained from determining the time to reach equilibrium even though this may require 2 or 3 months in some cases.

Since 1966, Cairns and a number of associates, (principally Dr. William H. Yongue, Jr.) have been carrying out investigations involving the colonization of polyurethane foam anchored in various portions of Douglas Lake, Mich., (e.g., Cairns, et al. 1969, 1973; Cairns and Yongue, 1974) and other sections of the country ranging as far south as South Carolina (Yongue and Cairns, 1971). The purpose was to study the MacArthur-Wilson Equilibrium Model of the point at which the colonization rate is in rough equilibrium with the decolonization rate. A few years ago, when looking over the assembled data from 1966 through 1972, it became evident that the time required to reach an equilibrium between these two rates had been steadily decreasing in Douglas Lake, Mich., from an initial period of approximately 8 weeks to a period of approximately 2 weeks in 1974.

Examination of colonization rates and the time required to reach equilibrium from other locations strongly suggested a correlation between the degree of eutrophication of the lake or pond in question and the time required to reach equilibrium. Cairns (1965), in a year-long study of the Conestoga Basin carried out in 1948, noted that the initial response of a freshwater protozoan community to increased nutrient loading was to increase both the number of species and the number of individuals per species. Further increase in nutrients might then lead to a decline in the number of species, but not necessarily the number of individuals. This has subsequently been confirmed in a number of situations.

ZOOPLANKTON PHYSIOLOGY AND REPRODUCTION

In a time of increased power demands, more and more power plants are being constructed. Since large volumes of water are used for cooling these plants considerable attention has been focused on their effect on aquatic populations, especially fish. Very little work has been conducted on zooplankton, and many of these papers do not examine the interaction of temperature changes, chlorine, and physical damage. Most of these studies are only on acute mortality. Chronic studies are virtually nonexistent (Bunting, 1974). Various methods have been proposed to examine the effects of entrainment but no studies have been done to determine effectiveness and interrelatedness of the methods.

Such parameters as zooplankton physiology and reproduction might be useful in estimating the functional integrity of zooplankters in lakes near power plants. For example, oxygen consumption rates, ATP, and lipid concentrations could be changed. Filtering rate of zooplankters might also be determined by comparing algal counts at time zero and after a defined period of time (Buikema, 1973a) using the equation

$$F.R. = v \frac{\log_{10}c_0 - \log_{10}c_t}{\log_{10}e}$$

These factors all affect reproduction rates (Buikema, 1973b) which could be quantitatively assessed in a relatively short period of time. Because many zooplankters migrate vertically in response to changes in light intensity, such functional assessments as rates of migration (Gehrs, 1974), response thresholds, et cetera could be useful.

FUNCTIONING OF BENTHIC MACROINVERTEBRATE COMMUNITIES

Methods for the assessment of benthic macroinvertebrate community function have unfortunately lagged far behind the development of those for the analysis of community structure.

A great body of literature has been amassed recently, firmly establishing the energy supply of many running water systems as largely heterotrophic (Minshall, 1967, 1968; Vannote, 1970; Fisher, 1971; Hall, 1971; Kaushik and Hynes, 1968; Fisher and Likens, 1972; Cummins, 1972, 1973; Cummins, et al. 1973a, 1973b). Detrital-based ecosystems have been shown to be largely dependent upon litter from their terrestrial surroundings for nutrient input and even the evolutionary dispersal of insects (Ross, 1963). The processing of dead organic material passing downstream through a stream ecosystem is largely a function of primary decomposition by fungi and bacteria (Iversen, 1973), and the selective feeding on detritus by invertebrates following microfloral colonization and conditioning (Petersen and Cummins, 1974).

Aquatic macroinvertebrates are important components in food webs of aquatic systems, being primary and secondary consumers, and serving as food sources for higher trophic levels. Very little information exists on the functioning of macroinvertebrate communities, and even less concerning the influence of pollutional stress on feeding patterns of invertebrates. The loss of an individual in a community with a particular feeding pattern due to pollution and its effect on community function have not been investigated. More studies to develop methods for the assessment of macroinvertebrate community function are needed.

Identification of the importance of the major biological components in the process of reducing the initial detrital biomass could be accomplished by artificially selecting against specific components in simultaneous parallel experiments, e.g., according to their size. Evaluation of the importance of each of the components can be based upon a number of parameters including:

a. Standing biomass.
b. Calorific equivalents.
c. Efficiency of energy utilization.
d. Size of food particles required.
e. Specific interrelationships between the components.

If simultaneous parallel experiments are conducted concurrently under experimental (stressed) and control (absence of stress) conditions, patterns of the impact of stress should emerge.

AUTOTROPHIC AND HETEROTROPHIC FUNCTIONING

The autotrophic and heterotrophic components of aquatic systems have a vital and essential role in the regulation of the functional activities of aquatic systems. These two components of aquatic communities are intimately involved in nutrient cycling, energy fixation, and energy transfer. In order to understand and predict the functional capabilities of freshwater flowing systems, it is obvious that methods must be evaluated which allow a better understanding of the above activities.

The energetics of freshwater flowing systems depend upon two sources of carbon—carbon fixed internally via the photosynthetic activity of the autotrophic community and carbon which enters the system from the terrestrial environment (i.e., allochthonous material—leaves, et cetera). The utilization of either of the sources is generally the rate-limiting step in the total energetics of the whole aquatic system. In addition, the availability and utilization of essential inorganic nutrients in freshwater flowing systems are governed to a large extent by the autotrophic and heterotrophic components. While the autotrophic and heterotrophic microbial communities are frequently not studied in evaluating the impact of stress (pollution) on flowing systems, they have been shown to be sensitive and reliable indicators of environmental perturbation (Cairns, 1971). The reason that they have not been utilized extensively in pollution assessment in the past has been directly related to the difficulty in measuring their structure and function. However, it is essential that approaches be developed which allow us to understand and measure the responses of these vital components of aquatic systems.

A. Nitrogen Cycle—Procedures permitting an evaluation of the process and role of the nitrogen cycle in flowing fresh water should be further developed although some excellent references are available (e.g., Brezonik and Harper, 1969; Klucas, 1969; Kuznestor, 1968 and Tuffey, et al. 1974). The ability of microorganisms to enzymatically transform one chemical species into another is well known. For example CO_2 is reduced to organic compounds and condensed phosphates can be broken down into phosphates and then the phosphates can be coupled to organic molecules to form some extremely important biological molecules. However, nitrogen appears to be utilized in more forms by living organisms than any other element.

Nitrogen can exist in six different valence states and all six of these states can be utilized or produced by microorganisms. In some cases there are specific organisms for specific ionic species such as nitrifying bacteria for NH_3 and NO_2 or nitrogen fixers for N_2. On the other hand a myriad of organisms may use NH_3 or NO_3. Microorganisms are also known to produce NH_3, NO_2, NO_3, N_2 and organic nitrogen compounds. Quite obviously microorganisms play an important role in the nitrogen cycle, and nitrogen plays an important role in the life of living organisms.

The investigation of the nitrogen cycle or balance in a stream or lake is a viable approach for studying functional responses at the microorganism level because: 1) many if not all of the enzymatic reactions involved in the nitrogen cycle are heat sensitive; 2) many of the reactions are sensitive to heavy metals; 3) many are directly affected by oxygen levels; and 4) the analytical methods for investigating the microorganisms involved in the N cycle are fairly well known.

B. Carbon Cycle—Rates of carbon uptake and incorporation are integrally involved with structure and function of autotrophs and heterotrophs in aquatic systems (Patrick, 1973; Bott, 1973). Knowledge of these rates yields information vital to the understanding of carbon cycling and assimilative capacity in diverse freshwater flowing systems which are subjected to pollution (Saunders, 1971; Wetzel and Rich, 1973). Numerous techniques have been developed utilizing radioisotopes and the stoichiometric relationship between oxygen consumed or produced in the system to carbon oxidized or reduced (Vollenweider, 1969; Hobbie, 1971). Enough variation exists in current investigations to make comparisons from investigation to investigation exceedingly difficult. The development of acceptable techniques which are efficient and can be utilized in a variety of situations is overdue. Data collected using a somewhat universal and standard technique or method would be comparable to data collected in the same manner in other investigations. The value of such an approach could be realized in information gained from the statistical comparisons of diverse aquatic systems and pollutional regimes (Steel and Torrie, 1960).

In an effort to develop such methodology for determining the role of carbon in freshwater flowing systems, a variety of old and new techniques might be examined. This could include development of equipment and test chambers, evaluation of the efficacy of neutron activation analyses, autotrophic indices, plant and animal carotenoids, other pigments (xanthophylls, phycobilins, et cetera), ATP analyses, and other procedures (Margalef, 1960; Thatcher and Johnson, 1973). The development of procedures with the little-used isotopes (^{35}S, ^{33}P, et cetera to determine functioning of the heterotrophic and autotrophic components could also be investigated (Bott and Brook, 1970).

C. Sulfur Cycle—One might develop a method to differentiate heterotrophic and autotrophic function via the preferential utilization of organic and inorganic sulfur. Sulfur, as one of the macronutrients and an almost universal component of proteins, may be intimately involved with structure as well as function of flowing aquatic systems. Knowledge of uptake rates and utilization by the heterotrophic and autotrophic components may yield valuable information about reaction rates and critical concentrations in these compartments (Vollenweider, 1969). Sulfur has recently been cited as a critical factor in the acidity of rainfall and runoff, pollution from acid mine drainage, and release or leaching of nutrient cations such as calcium from the soil into aquatic systems (sulfate is the most common inorganic species in flowing systems). Many microorganisms and plants have the capacity to reduce sulfate to the oxidation state of sulfide for incorporation into organic materials such as the amino acids, cysteine and methionine (Rodina, 1972).

The differential metabolism of sulfur by heterotrophs and autotrophs in aquatic systems could be determined using SO_4 and tagged amino acids. Changes in community structure above and below polluting discharges could be monitored. It has been shown that bacterial diversity and algal diversity are reduced by thermal discharges (Guthrie, et al. 1974). Rates of sulfur metabolism above and below thermal effluents may be correlated with changes in diversity and may be directly involved with the assimilative capacity of that reach of the stream.

HISTORIC PROSPECTIVE

Even if we quadrupled the number of methods available for the quantification of biological integrity, a very basic question will not be resolved—namely, what type of system will be used to provide the baseline or reference numbers against which systems receiving industrial waste discharges or other forms of contamination may be compared? The selection process is likely to be hampered by our failure to recognize that most of the continental United States, particularly the area east of the Mississippi, is a man-altered environment. Two illustrations will suffice to make this point.

Each summer a number of students and faculty members (frequently including me) journey to the northern tip of Michigan's lower peninsula to spend a few months studying "natural" ecosystems at the University of Michigan Biological Station. Students and faculty are cautioned not to overcollect and upset the balance of nature. I remember vividly a stormy faculty session many years ago when one faculty member proposed experimental clearcutting on the station tract which was hotly contested by another faculty member who wanted to preserve the "natural environment" for certain plants. The present station director, David M. Gates, who spent his boyhood at the station, remembers from personal observation and from the journals of his plant ecologist father, Frank Gates, the devastation that resulted from the vast lumbering activities characteristic of that area less than 100 years ago. Journals of early biologists report that it was almost impossible to travel anywhere in the area during the logging period without seeing slash fires or smoke from them. Originally the Biological Station area was used by civil engineers because the vegetation had been so thoroughly destroyed that long lines of sight were possible. Only when the vegetation became partially reestablished and interfered with surveying was the area turned over entirely to biologists.

The second example is the area roughly between Allendale, S.C., and Augusta, Ga., known as the Savannah River tract. This site was placed off limits in approximately 1951 by the Atomic Energy Commission. At this time the inhabitants of the town, Ellenton, and the other parts of the area were removed and the farms, homesites, et cetera were mostly allowed to revert to "natural conditions" following a brief occupancy by work crews during the construction phases. Some trees were planted and other assists were given to natural reinvasion, but mostly the process of change was "natural." Today the area abounds with wildlife and is and has been the focus of many ecological surveys and studies. Were it not for the AEC facilities still there, most ecologists would not hesitate to consider this a natural system and for the vast portions of the tract where no manmade structures are present, most ecologists would have no hesitation in carrying out an extended study of a "natural system." The point of all this is that what we are willing to label as "natural" systems often were at one time substantially altered by human activities and frequently underwent severe ecological perturbations before reaching their present state. Thus, we should not hesitate to use as reference systems those we consider satisfactory even if they were once altered by human activities.

ANTHROPOCENTRIC CRITERIA

One might also characterize biological integrity by determining the ability to produce desired quantities of commercially or recreationally desirable species. This could be quantified by comparing actual yield against an optimal yield. This might also be done for pest or nuisance species such as biting insects or algae that produce unpleasant tastes and odors in water supplies. Quantification in terms of aesthetically desirable species boggles the mind.

MANAGEMENT CRITERIA

Using the anthropocentric criteria discussed above, one might also quantify the energy and material required to maintain the desired crops or low densities of pest organisms. One might rate a system from 1 to 10 on whether it provides desirable conditions "free" (i.e., no management costs) or whether it is a costly system to manage. This might be considered an operational definition of biological integrity.

ASSIMILATIVE CAPACITY

For the purposes of this discussion assimilative capacity is defined as the ability of a receiving system or ecosystem to cope with certain concentrations or levels of waste discharges without suffering any significant deleterious effects. I have attempted to find other definitions of assimilative capacity but unfortunately have failed to find any significant body of literature on this subject.

A common position of those denying that assimilative capacity exists is that an introduced material will cause a change that would not have otherwise occurred. There is an implication that any change is necessarily deleterious. It would not be rational to deny that an ecosystem or a community of organisms will respond to an environmental change whether caused by the introduction of wastes from an industrial process or a leaf dropping into the water from a tree. It seems to the detractors of the concept of assimilative capacity that the introduction of chemicals and fibers in the form of a leaf is not regarded as a threat to the biological integrity of the receiving system (i.e., the maintenance of the structure and function of the aquatic community characteristic of that locale) but that the introduction of the same chemicals and fibers via an industrial municipal discharge pipe would be deleterious. Some of the same chemicals and materials present in leaves and other materials introduced naturally into ecosystems are also present in the wastes from industrial and municipal discharge pipes. Surely, within certain limits, an ecosystem can cope with these. Of course, for bioaccumulative materials such as mercury, the assimilative capacity of many receiving systems is almost certainly very low and for some probably zero. Zero discharge of these types of polluting materials is a highly desirable goal which should be achieved with dispatch. For other types of materials the case against assimilative capacity appears to have no logical framework.

The weaknesses of the argument against the use of nondegrading assimilative capacity are especially weak where heated wastewater discharges are concerned. Would a ΔT of 0.001°C damage the biological integrity of the Mississippi River at New Orleans or the Atlantic Ocean near Key West, Fla.? Or to phrase the question somewhat differently, would this thermal addition of industrial origin be more of a threat or even a measurable threat to the biological integrity of these ecosystems than the natural thermal additions? Is a microgram of glycolic acid placed into an ecosystem by an algal population less of a threat to the biological integrity of an ecosystem than the same amount discharged from an industrial or municipal waste pipe? If you believe that there are some ecosystems into which this amount of heat or glycolic acid might be introduced without damaging the structural or functional integrity of the ecosystem, then you cannot deny the existence of assimilative capacity even if there are a very limited number of ecosystems for which you think this is possible.

A second aspect of the assimilative capacity controversy is the belief of some environmentalists that the ecological effects of society's activities, particularly those of industrial origin, can be forever contained. The position of people who proclaim that we can have an industrial society from which nothing may be introduced into ecosystems is irrational. If one's outlook is towards treating each waste discharge in isolation from all others, rather than viewing it regionally, then it is quite evident that the complete treatment of industrial wastes will require substantial amounts of energy, an enormous capital investment in facilities, and a variety of chemicals to facilitate the treatment process if the process water is to be recycled for further use. This energy, chemicals for treatment, and materials for the construction of additional treatment facilities will all have to be produced somewhere and the production process will produce heat and other waste products that cannot be forever contained.

The critical question is not whether they can be introduced into the environment, thus taking advantage of its assimilative capacity, but rather how and where they should be introduced into the environment. If the detractors of the assimilative capacity approach believe that it is possible to have an industrial society without introducing anything into the environment at any place or time then they should show us in a substantive way how this can be done. If they cannot do this, then we should all collectively address the problem of determining the assimilative capacity for different types of waste products and ecosystems rather than endlessly discussing whether assimilative capacity does or does not exist. If the antagonists of the concept of assimilative capacity believe that there is no way in which a harmonious relationship between an industrial society and ecosystems can be achieved then they should tell us in more detail what to do next.

There is no question that the use of assimilative capacity increases the risk of damaging the biological integrity of the receiving system. Even the use of nondegrading assimilative capacity reduces the safety factor and this, together with the variability in assimilative capacity caused by changing environmental conditions, makes it essential that continuous biological monitoring be used by dischargers taking advantage of assimilative capacity. Thus, management and monitoring costs are inevitable but may often be less expensive than advanced waste treatment costs.

RESISTANCE TO AND RECOVERY FROM CHANGE

A. Resistance to Change—Some biological communities have a greater inertia or resistance to disequilibrium than others. The ability to resist displacement of structural and functional characteristics is a major factor in the maintenance of biological integrity. In order for a displacement to be categorized as a loss of integrity it would have to exceed the range of oscillations or fluctuations characteristic of that system. [illegible] sufficient funds and time are available these natural fluctuations can be determined with reasonable accuracy. The stress required to overcome inertia is less easily determined until an actual displacement has occurred, although one might make an estimate from dose-response curves of important indigenous organisms. However, the use of the "species of interest or importance to man" concept is dangerous since the response of that species to a particular stress might not be representative of the response of other species in the system. At present we have no reliable means of quantifying this important characteristic of biological integrity. A very crude estimate of inertial rank ordering of major water ecosystems is given in Table 1 (from Cairns, 1974).

Table 1.—The relative elasticity (ability to return to normal after being displaced or placed in disequilibrium), inertia (ability to resist displacement or disequilibrium), and environmental stability (consistency of chemical-physical quality).

	Elasticity	Inertia	Environmental stability
Lakes	2	3	2
Rivers	1	2	3
Estuaries	3	1	4
Oceans	4	4	1

1 = high
2 = intermediate high
3 = intermediate low
4 = low

B. Recovery from Stress—Once a system has been displaced (i.e., altered structurally or functionally) the time required for the restoration of biological integrity is important as are the factors which affect the recovery process. Accidental spills such as the ones reported by Cairns, et al. (1971, 1972, 1973), Crossman, et al. (1973) and Kaesler, et al. (1974) for the Clinch and other rivers will probably always occur in an industrial society. A crude index of elasticity (i.e., ability to snap back after displacement) has been developed by Cairns (in press). A list of the factors important to this index follows:

a. Existence of nearby epicenters (e.g., for rivers, tributaries) for reinvading organisms.

Rating system—one = poor; two = moderate; three = good.

b. Transportability or mobility of disseminules.

Rating system—one = poor; two = moderate; three = good.

c. General present condition of habitat following pollutional stress.

Rating system—one = poor; two = moderate; three = good.

d. Presence of residual toxicants following pollutional stress.

Rating system—one = large amounts; two = moderate amounts; three = none.

e. Chemical-physical water quality following pollutional stress.

Rating system—one = severe disequilibrium; two = partially restored; three = normal.

f. Management or organizational capabilities for immediate and direct control of damaged area.

Rating system—one = none; two = some; three = thriving with strong enforcement prerogatives.

Using the characteristics listed above, which must be placed into the equation in exactly the sequence in which they are given, one can arrive at a rather crude approximation of the probability of relatively rapid recovery. This would mean that somewhere between 40 and 60 percent of the species might become reestablished under optimal conditions in the first year following a severe stress, between 60 and 80 percent in the following year, and perhaps as many as 95 percent of the species by the third year. Natural processes with essentially no assistance from a management or a river basin group accomplished this on the Clinch River spills which were studied by the Aquatic Ecology Group at Virginia Tech and the usefulness of this estimate has also been checked with data provided by some acid mine drainage studies (Herricks and Cairns, 1972, 1974a, 1974b) and seems adequate in this regard as well. The equation follows:

RECOVERY INDEX = $a \times b \times c \times d \times e \times f$
400+ = chances of rapid recovery excellent
55-399 = chances of rapid recovery fair to good
less than 55 = chances of rapid recovery poor

During the development of the simplistic equation just given, considerably more complicated equations were considered and rejected because the refinements seemed meaningless in view of our present state of knowledge. On this basis one might reject even the modest effort just made. On the other hand there seems to be a very definite need to formalize the estimation of recovery and one hopes that more precise equations properly weighted will evolve from this modest beginning.

CONCLUSIONS

It is evident that no single method will adequately assess biological integrity nor will any fixed array of methods be equally adequate for the diverse array of water ecosystems. The quantification of biological integrity requires a mix of assessment methods suited for a specific site and problem (e.g., heated wastewater discharge). Since some ecosystems are more complex than others and some stresses on biological integrity more severe than others the variety and intensity of methods used should be site specific. Table 2 demonstrates a simple version of a decision matrix for resolving these problems.

Table 2.—Potential threat to biological integrity.

Ecosystem Complexity	Minor 1	Moderate 2	Serious 3
Simple 1	1	2	3
Intermediate 2	2	4	6
Complex 3	3	6	9

A number one situation would require less effort and fewer criteria than a number nine. Many ecologists will be unwilling to make the value judgments necessary for even the simple example matrix. Unless they dispute the assumptions which preceded the matrix, professional pride should force them to do so because otherwise they will be forcing industry to overassess as a result of their insecurity and inability to make distinctions between difficult and simple situations.

What is needed is a protocol indicating the way in which one should determine the mix of methods that should be used to estimate and monitor threats to biological integrity. A good example of this approach is "Principles for Evaluating Chemicals in the Environment" (originally "Principles of Protocols for Introducing New Chemicals into the Environment") published in 1975 by the Environmental Studies Board of the National Academy of Sciences. A badly needed accompaniment is a national system for storing data gathered for such purposes which also insures greater standardization and compatibility than is possible with present systems. It is also important that industrially sponsored studies of this kind be made more accessible to the academic community. This would insure that shoddy contractors would be exposed by academic criticism and reduce the money wasted by industry on these groups and would also expedite advancement of this type of assessment which would also benefit industry.

While additional methods for quantifying biological integrity are being developed, industry and other dischargers into aquatic systems can take immediate measures to protect ecosystems. Until all currently available methods have been used there is no justification for complaining about the lack of appropriate methodology. A list of some useful methods follows: (1) A screening test such as the ORSANCO 24-hour test to determine which wastes require immediate attention and which may be relegated to a lower priority. (2) A determination using the ORSANCO 24-hour or some other short term test of the variability of waste toxicity. Although there is some variability in bioassays due to the nature of the test organisms, it is dwarfed by the variability in toxicity of most industrial wastes. Some wastes may vary in toxicity as much as 10,000 times from one sample to another. (3) A baseline ecological survey which is essentially an inventory of biological, chemical, and physical conditions in the receiving system, should be carried out at critical points related to the discharge with, of course, an unexposed area to serve as a reference or control. (4) A biological monitoring of certain areas of the receiving system on a routine basis so that any deleterious effect can be determined rapidly.

There exists a vast array of methods potentially suitable for the assessment or determination of biological integrity, both structural and functional. One generally, though not invariably, realizes the importance of the biological entity being measured, although even this is not always the case. However, showing that it is useful in the context of measuring changes in biological integrity is another matter. This is where biologists and ecologists have usually dropped the ball.

Most biologists and ecologists with classical training do not feel any responsibility to justify the appropriateness of a method or a parameter being suggested as a monitor for biological integrity, because they assume that if it is useful in ecology, and if classical ecologists recognize the importance of the measurement, then it must be appropriate for the assessment of biological integrity. We have all seen the endless "shopping lists" resulting from a group of ecologists putting together a list of parameters to determine the ecological impact of a particular activity such as the construction of a dam. The methods often appear to be assembled by a "stream of consciousness process," or each of the ecologists present flushes his or her mind of all the methods known to him and requests that determinations be made.

Even when all this information is collected, classical ecologists will often refuse to predict the consequences of the course of action anyway because the information is often not gathered in an orchestrated fashion so that the data bits can be integrated and correlated. On such projects each investigator goes his or her own way with little or no communication with other investigators or even a feeling of responsibility to see that data are gathered so that the needs of this particular assignment will be fulfilled. What results is a series of inventories of varying scientific sophistication which are practically never useful for modeling or predictive purposes.

The determination of biological and ecological integrity is also hampered by the focus of attention on "pipe standards" rather than "receiving system standards." Thus, relatively little grant funding has been available from either governmental or private sources to develop methods for the quantification of the effects of pollution on biological integrity. One can obtain funding for purely "ivory tower" ecological research, but if one made the major thrust of this research the assessment of pollutional effects, it would almost certainly be disallowed by the more "ivory tower" funding agencies. Mission-oriented agencies have been focused on "pipe standards" rather than on "receiving system standards" and on chemical-physical measurements rather than biological measurements. Although it was in industry's enlightened self-interest to support the development of such methods, funding from this source has historically been trivial.

In addition to these difficulties, until recently there were relatively few scientific outlets for publication of such investigations and very little academic prestige attached to their production. As a result, most of the work was carried out by consulting firms or academic institutions which produced proprietary mimeographed reports of their investigations. Thus, what little knowledge was generated in this field generally has been given very limited distribution in the form of proprietary reports which were rarely subjected to peer review and certainly did not go through the rigorous scrutiny that occurs when publication is through the usual academic outlets and subjected to printed rebuttal, et cetera.

A brief statement of my own view of the conditions which produced our present state of disarray regarding the quantification of biological integrity follows. We do not know, in any scientifically justifiable sense, the characteristics of aquatic ecosystems which are essential to the maintenance of biological integrity. We also know practically nothing about the relationship between the structural and functional characteristics of natural ecosystems. Such factors as spatial distribution of species and the factors which cause systems to oscillate both in structure and function are so poorly documented that it is difficult for us to say what is desirable and what is undesirable except in the grossest way. Furthermore, most of the systems in the continental U.S. and particularly that area east of the Mississippi River have been in many ways substantially affected by man-initiated activities such as deforestation, flood control, agricultural activities, and so forth. Therefore, most of the systems with which we must work are already disturbed to some degree.

However, all is not lost! Most of the ecosystems in England, for example, have been influenced by human activities for generations and yet we find them pleasing and acceptable. Other systems such as the Thames River were once sufficiently degraded to be an objectionable nuisance and have been restored by planned reclamation efforts to a condition which, if not comparable to the primitive or original condition, is nevertheless more pleasing and more acceptable as well as more useful to us socially.

We are also able to estimate with reasonable precision the concentrations of toxicants which permit survival and adequate function of aquatic organisms which we consider important or representative. Given our present situation with a proliferation of chemical materials and a paucity of information on their toxicity, we might use as a reasonable working hypothesis that concentrations of chemicals and other potentially toxic materials permitting survival coupled with adequate growth and reproductive success will also permit the organisms to function reasonably well in other important respects.

We also know that aquatic communities subjected to pollutional stress will undergo structural alterations of a predictable nature. We know that the number of species will be reduced and that the number of individuals in certain species may increase. We can assess, on a site specific basis, such important behavioral characteristics as the temperature preference and avoidance of fish. Although the methodology for the assessment of biological integrity certainly could be markedly improved, the use of the methodologies in which we have confidence and a long history of effectiveness is still miniscule.

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DISCUSSION

Comment: I've been fascinated with some of the work that you and your students have been doing using individual fish or small groups of fish to monitor changes in water quality. At the outset of your talk, you indicated that you didn't feel that single species could be used in a measure of biological integrity. Would you comment on that?

Mr. Cairns: You're perfectly right. I probably should have covered this in the talk and it is in the paper. Single species are not a good index of biological integrity but can be used in an "early warning" system. The purpose of the single species in our in-plant monitoring systems is to give an early warning of toxicity before the wastes actually reach the receiving system. This has some advantages but also all of the disadvantages of a "representative" species.

If an in-plant monitoring system showed biologically deleterious changes in the plant waste before it reaches the river, then you would have several options: (1) Shunt the waste to a holding pond; (2) recycle the waste for further treatment; (3) scale down the plant operations until the signal disappears.

This in-plant information would have to be correlated to the response of the biological community in the receiving system itself. That is the way it should be used—not as a single species index standing alone.

Perhaps I'm being too much the devil's advocate in not relying on individual species. However, it is dangerous to over-rely on individual species. There is a role for them in in-plant monitoring systems, but never without being coupled to some monitoring system based on community structure in the receiving system itself. Our in-plant and in-ecosystem monitoring units are designed to be coupled together.

Comment: I was intrigued by your reference to using natural systems to accomplish tertiary treatment, as opposed to manmade systems to accomplish the less costly primary and secondary. Were you referring only to non-toxic kinds of materials as opposed to relying on nature to handle, say, chlorinated hydrocarbons and heavy metals? Also, do you feel that there is sufficient natural assimilative capacity to handle all of man's municipal and industrial wastes beyond secondary treatment?

Mr. Cairns: There are several points to be made here. One is that it may not be possible for many systems to handle all of man's wastes because they are too small and/or they are already overloaded. One would have to decide on a site specific basis.

As you point out, there are certain kinds of compounds which are neither degraded nor dispersed; these may undergo biological magnification and for these there is zero assimilative capacity. However, for most wastes many ecosystems have some assimilative capacity despite the zero discharge philosophy which assumes that one can forever contain the environmental effects of an industrial society. This is not possible because very, very advanced treatment requires energy, chemicals, and equipment.

The production of these will, ultimately, produce environmental effects somewhere. They will just be displaced from one site to another. I was trying to address that point in a very simplified fashion, but if there's no such thing as a natural assimilative capacity, we're in real trouble! That would mean the end of industrial society. So even though we have mostly anecdotal evidence and intuitive feelings that there is such a thing as assimilative capacity, we have no other choice but to assume nature can assimilate certain types of wastes and transform them. But if we don't define assimilative capacity more vigorously the assimilative capacity is exceeded and then the ecosystems will collapse.

We might set arbitrary standards for waste discharges based on general rules, and they might actually work and protect ecosystems, but then we'll be underusing the assimilative capacity most of the time. We will not be making full beneficial, non-degrading use of assimilative capacity, let's say, 364 days out of the year. Without information feedbacks about the condition of the receiving system good quality control is unlikely. My feeling is that the money spent on getting feedback of information about the response and condition of the receiving system would be more than offset by the savings in waste treatment if one linked the discharge operation to the receiving capacity.

So, what we should be trying to do, really, is mesh two dissimilar systems. One is an industrial system operating under, more or less, the market system and the ecosystem which is "controlled" by environmental variables. We should be trying to get these two systems working together in some optimal way for society's benefit; I feel that we can do much better than we're now doing in that respect.

Comment: The Agency's Water Quality Standards program, traditionally, has been based on providing levels for chemical parameters which is to provide protection for instream water quality and biota.

Do you feel that is an adequate system to provide protection for aquatic communities, or do you think instream levels of chemical parameters must be augmented by biological monitoring, some type of biological monitoring requirement in the water quality standards themselves?

Mr. Cairns: If you develop one standard for the whole country, this fails to consider how different ecosystems are in various regions and that these differences influence toxicity.

Another important factor is that one shouldn't regulate these toxicants individually and in isolation from others. We aren't exposed to toxic insults one at a time and as organisms we respond to the collective insults to our bodies (the smoke, contaminants in the water, and so forth). So do aquatic organisms and other organisms. The attempts to regulate one stress in isolation from the effects of other stresses won't work.

We should take advantage of the fact that natural communities summarize and integrate all these insults and give us a cumulative response. I agree that we should make some attempts to estimate the thresholds of toxicity for individual compounds since this is useful information. It is good predictive information, but ultimately we must go to the system itself and study the cumulative impact and the integrated response. I can't see any other way out.

Comment: I'd like to see you follow along a little in that. Can you give us an idea of what level of training would be necessary to have the toxic people go out and do this sampling that you suggested and, obviously, the money and manpower required to do that on a national scale?

Mr. Cairns: In today's dollars or tomorrow's dollars?

Comment: Take your pick.

Mr. Cairns: There are simple bioassays like the ORSANCO 24-hour bioassay. The round robins showed that it could be used by people who had no prior training. The sequential comparison diversity index can be used by people with no formal taxonomic training.

For such tests one can take high school graduates and, in one week, one can train them to produce useful, statistically reliable results.

These technical people do better with the simple tests than Ph.D's because the Ph.D's get bored and the other people don't. For simple tests can use relatively untrained people, as long as they are discriminating and dependable workers.

The aquatic ecology group at Virginia Tech has just developed a test using *Daphnia* for the American Petroleum Institute which can be run quite well by people who have had other types of formal training (such as chemical engineering, sanitary engineering) but with no training in bioassay methods.

To cut costs we are going to automation in our own lab. We have a unit using laser holograms which will probably identify 8,000 diatoms, when it's working at full effectiveness, in less than 10 minutes. Biologists, in general, have not taken advantage of computer technology and other types of technology to cut costs in water quality assessment.

The in-plant system that Dexter just mentioned is being installed at the Celanese Plant, Narrows, Va., with the Manufacturing Chemists Association. The capital investment for that, if you already have a mini-computer, will be about $26,000 and it can be operated by a high school graduate. The laser system would cost about $156,000 in today's dollars, but could be used by many plants. The cost per analysis using automation will be relatively slight.

For a complete stream survey using nine taxonomists, my guess would be $4,000 to $8,000 per station for each examination. The "complete physical" surveys are very expensive. Functional measurements could also be expensive, except for the simple rate processes.

Comment: We're not only an industrial society, we're largely an urban society. There're a great number of these sections doing area-wide studies, an awful lot of them underway around St. Paul.

Many of the streams in urban areas are subject to large sediment loads, lots of scouring due to runoff a priori. Can we establish biological integrity with those kinds of streams, because if the locals are going to be added, they will have to choose between alternatives. They will need some measure of what thought, or the possible results to those alternatives when you're talking about control of runoff, perhaps treatment and other kinds of disposal that are in place now.

Do we have to take the physical scenarios of physical alterations for improvements? The same thing on chemical, do we equate those and then try to come up with the biological scenarios and possible results, and then just lay them out and take your chances?

Mr. Cairns: I don't know if there is anybody here that can answer your question.

My guess would be, if I understood your question correctly, that in systems like the Ohio we'll never find out the original condition, so we must set standards (chemical, physical, and biological) that are satisfactory to us as a society. The various scenarios with cost-benefit analyses can be given to the general public or other decisionmakers for final choice.

If you look at the ORSANCO reports it is evident that the general water quality trend has been toward improvement of chemical-physical characteristics and they are getting more stable and more predictable. This resulted from an implemented regional scenario.

Comment: I was talking about any of the much smaller water bodies that are around the country. We only have a few very large systems. In many areas the streams are much smaller, they're creeks, and bodies down to that size.

A great deal of money could be spent, but we have to base some decision on biological integrity.

Mr. Cairns: We're studying the South River with DuPont in Virginia. It's a very small stream with very heavy waste loading. I believe we can evaluate biological integrity for this stream and develop practical management programs to either improve or maintain present condition of integrity.

It would not be cost effective to restore that stream to its original condition, but I think it is reasonable to restore the stream to some more acceptable condition before it joins the Middle and North Rivers to form the South Fork of the Shenandoah River. There are acceptable means of determining biological integrity and developing management plans. Implementing then is another matter.

MODELING OF AQUATIC ECOSYSTEMS

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INTRODUCTION

Public participation in environmental planning and in the decision processes that lead to implementation of specific control actions or projects, has compelled tradition-bound planners and designers to re-examine their techniques and tools. It is essential in today's world that the range of alternative actions and/or strategies be widened, and that all viable choices that the body politic wishes to consider be assessed before the choice be made. This is no small task, in view of the complexity of the environmental system, the many constraints—economic, social, political, and technological—that must be considered, and our own limitation in understanding how our environment actually behaves. An awareness of these factors may cause the more timorous to abandon all hope, but stimulate the more adventurous to seek new techniques, methodologies, and tools for dealing quantitatively with environmental management alternatives. Models of aquatic ecosystems are representative of such new tools. Properly conceived and structured, they can become valuable adjuncts to the environmental planner's intuitive judgment and can be made to serve the public decision process. It is our intention in the discussion that follows to illustrate how such a tool may come into being and how it may be used.

We propose, first, to present some basic notions concerning the behavior of the aquatic environment we wish to model. Then, we would like to show how these can be treated conceptually to form the model. Given that such a model can be implemented (and we will assert that it can, by citing actual examples), we will illustrate its potentials by demonstration in an actual case study, Lake Washington.

IMPORTANT ECOLOGICAL CONCEPTS AND PROCESSES

EUTROPHICATION

For the purposes of illustrating the development and utility of an aquatic ecologic model, let us consider an environmental management problem of current national interest—that of eutrophication of lakes.

Eutrophication, the process of "aging" of lakes, that ultimately leads to the conversion of a lake into a swamp, is governed by many interrelated physical, chemical, and biological processes that may be modified by man. It is manifest to the non-scientist in the form of extreme symptoms—proliferation of aquatic weeds, algal blooms, and fish kills. However, to the trained biologist it is seen as a delicate but complex imbalance between the nutrient supply to the system and indigenous life forms. This imbalance may be a natural consequence, a slow inexorable progression of nutrient enrichment of the lake keyed to geologic and climatic changes, or it may be artificial, accelerated by man through imprudent intervention in the lake's natural hydrologic regimen, its ecosystem, or its nutrient supply.

THE HYDROLOGIC SYSTEM

A fundamental building block of the lake ecologic model is a capability to represent correctly the hydrologic processes that determine the exchanges and balances of water, heat energy, and nutrients. Such a capability may be available in the form of data obtained by direct observation or may be represented by another model, a hydrologic or hydrodynamic "driver," that can simulate prototype behavior. The minimum information we will need from this source includes temporal and spatial descriptions of water movement and temperature. A number of suitable models that will satisfy these requirements have been developed and successfully applied in studies of thermal energy balances in lakes and reservoirs. We will not attempt to describe these here, but will refer the interested reader to the rather substantial body of literature already extant.[1,2,3]

THE ECOSYSTEM

An aquatic ecosystem may be defined explicitly in terms of specific living organisms and the environment in which they live, including its spatial dimensions and quality. However, for purposes of model representation of ecosystems—of whatever form and complexity—in the specific environments of a lake or reservoir, we may be well advised to consider first some general principles and processes that seem to be common to such aquatic ecosystems. As an aid in conceptualizing the problem, a diagrammatic representation of important ecologic interrelationships and processes for a lake environment is shown in Figure 1.

First, let us recognize that the primary source of all energy to "drive" the ecosystem and to regulate life processes is the sun. The sun's energy is delivered to the aquatic environment as solar radiation that passes through the air-water interface and is distributed downward in accordance with clarity and absorptive capacity of the water. If photosynthetic plants are present, this supply of energy, together with certain fundamental building blocks for all living organisms, can be transformed by the process of photosynthesis into biomass, i.e., living matter. Such biomass, created by the so-called *primary producers,* represents a potential energy source for higher forms of life who may by metabolic processes transform it into their own biomass. This they may accomplish at some net expenditure of energy that may be treated as a gain in entropy for the system as a whole.

In a complex aquatic habitat we may identify four general groupings of life forms according to their particular role in maintaining a viable ecosystem. These are:

1. *Abiotic substances,* including those essential as building blocks of biomass, such as the most elemental forms of carbon, nitrogen and phosphorus; and those that are necessary to sustain life, such as dissolved oxygen and trace elements.
2. *Primary producers,* including autotrophic organisms such as phytoplankton that can incorporate abiotic substances into living cell material by the process of photosynthesis.
3. *Consumers* (predators), including heterotrophic organisms such as zooplankton and aquatic animals (nekton and benthic forms) that utilize other biota and organic residues as basic energy sources; and
4. *Decomposers,* including bacteria in both liquid and solid (benthos) phases and fungi that break down residual organics to abiotic forms or to forms that may be more readily utilized by consumers.

PRIMARY PRODUCTION AND PHOTOSYNTHESIS

The aquatic ecosystem functions under constraints of the availability of certain basic substances, e.g., carbon, nitrogen, and phosphorus, and environmental conditions, e.g., light, heat, toxicants, et cetera that may be regulated exogenously. In addition, the quality of the environment, determined in part by the ecosystem itself, may set limits on the system's performance. For example, the failure of decomposers to break down organic matter accumulated in the benthos may bring on an anaerobiosis with attendant depression of dissolved oxygen and formation of soluble toxic compounds.

Primary producers, like free-floating algae or attached aquatic plants, utilize the sun's energy and abiotic substances to synthesize new cell material through photosynthesis. A relatively simple definition of the photosynthetic process is given by the approximate stoichiometric equation

$$5.7\,CO_2 + 5.4\,H_2O + NO_3^- \xrightarrow[\text{algal cells}]{\text{light}}$$

$$C_{5.7}H_{9.8}O_{2.3}N + 8.25\,O_2 + OH^- \qquad (1)$$

This relationship is derived from a basic consideration of the driving mechanisms of photosynthesis and empirical evidence as to the approximate composition of algal cell material (neglecting phosphorus and trace elements). While the actual process is far more complex than the equation suggests, most of the basic factors that relate algae to their aquatic habitat are represented. It is seen that the essential driving force for the process (reaction) is solar energy (light). Algal cells are capable of utilizing this energy source to build new cells from carbon dioxide, water, and nitrate. In the process, elemental oxygen is given off and an alkaline environment (often favorable to optimal algal growth) is created. Oxygen goes into solution and thus facilitates maintenance of an aerobic aquatic environment. Assuming the reasonableness of the equation stoichiometrically, we may estimate that about 1.9 mg/*l* of dissolved oxygen are produced for each mg/*l* of new cell material. Similarly, for each unit of oxygen produced, an approximately equal weight of carbon dioxide must be available.

GROWTH, RESPIRATION AND MORTALITY

The process described by equation (1) is essentially one of phytoplankton growth, an increase in biomass. But, as for all living things, life is sustained on a steady basis by utilizing stored energy, the process of respiration. This occurs more or less continuously, but is the dominant process when photosynthesis stops, i.e., in the absence of light. Respiration may be treated as a loss of biomass, normally at a rate of 5 to 15 percent of total growth.

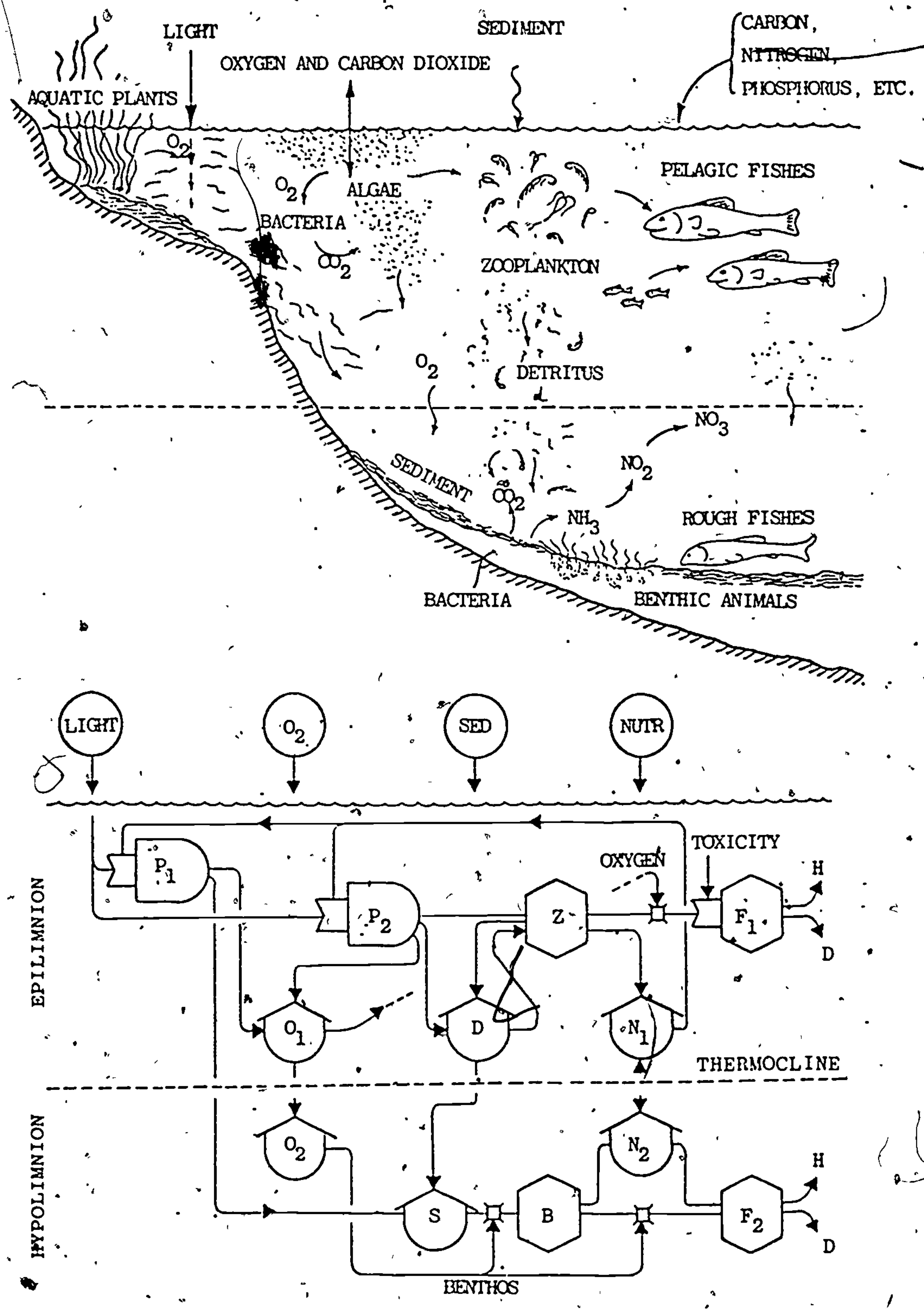


FIGURE 1.—Ecologic relationships in a lake environment.

Algal cells grow, respire; mature, and die. Mortality rates depend on environmental conditions; i.e., heat, toxicants, et cetera, and since these are likely to vary seasonally, mortality may at times dominate the life processes of algal cells.

The rates of algal growth, respiration, and mortality determine the net rate at which the total population, the standing crop, changes. This may be expressed simply by

Net Growth Rate of Biomass = [Growth−Respiration−Mortality]

Each of the terms representing growth, respiration, and mortality may be modified by factors that indicate the influences of the environment, for example, temperature, toxicity, and the availability of essential nutrients.

ALGAE-BACTERIA SYMBIOSIS

The loss of viable algal cells from the system means a loss of biomass in a complex form not readily utilizable by other biota, certainly not by algae themselves. To maintain the ecosystem in a viable condition in the face of limited supplies of essential nutrients, it is necessary to break down dead algal cells and return basic nutrients to the system in abiotic form. This is the role of the decomposers, who live in a symbiotic relationship to primary producers.

Consider the biodegradation of an organic compound (dead algal cells, for example) comprised essentially of C, H, O, and N. In an aerobic environment bacterial decomposition of such a compound might proceed generally according to

$$\underset{\substack{\text{organic}\\ \text{matter}}}{C_aH_bO_cN_d} + \underset{\text{oxygen}}{A\,O_2} \xrightarrow[\text{bacteria}]{\text{heat}}$$

$$\underset{\substack{\text{carbon}\\ \text{dioxide}}}{x\,CO_2} + \underset{\text{water}}{y\,H_2O} + \underset{\text{ammonia}}{z\,NH_3} + \text{new bacteria cells} \qquad (2)$$

This statement of the decomposition process indicates that proteinaceous material may be oxidized biochemically to produce carbon dioxide, water, and ammonia. The oxygen needed may be supplied, in part, by photosynthesis (equation (1)) while the CO_2 produced goes into solution to contribute to the reservoir of this basic requirement for algal growth. Ammonia may be further oxidized by bacteria to nitrite and then to nitrate; likewise contributing to algal needs. The symbiosis between bacteria and algae is the fundamental relationship between decomposers and primary producers.

PREDATION

Grazing by higher trophic levels plays an important role in regulation of populations at lower levels while propagating energy upward in the food chain. For example, rapid growth of algae may trigger a corresponding but somewhat slower reaction in zooplankton standing crops, increasing the availability of their primary food supply. Generally, the higher trophic level grows slower and is less efficient in energy conversion, so biomass (energy) is lost from the ecosystem. Peak growth of the predator occurs later, lags that of the prey, and fluctuations in biomass are usually not so great. Also, zooplankton may seek alternative food sources, for example, organic detritus, when algae are not plentiful. They have a certain motility, at least vertically in the system, enabling them to be somewhat discriminatory in what they eat.

A predator may shift its feeding preference from time to time, depending on environmental factors and availability of food supplies. For example, zooplankton may prefer algae, but when stocks run low, due perhaps to over-grazing, they may shift to detritus as a food source. These relationships can be incorporated in the ecomodel structure by making the growth in biomass of the predator a function of the availability of both the prey and the alternative food source. The rate of change in prey biomass will accordingly be diminished by loss to predation, with an allowance for the "digestive efficiency" of the predator in converting the prey's biomass to his own.

ENVIRONMENTAL LIMITS ON GROWTH

Light

Photosynthesis requires light and the rate at which the process of energy conversion to biomass takes place is regulated by light intensity. In the absence of light, or at very low levels of intensity such as may exist deep in a water body, there can be no primary production. Thus, photosynthesis is keyed closely to diurnal and seasonal fluctuations in radiation, and is affected by environmental conditions that may inhibit the transmission of light into the habitat of photosynthetic plants. For example, the suspension of solid matter in the water, either by natural forces or by the actions of man, may inhibit photosynthesis or cause it to cease altogether. In certain instances, even the excessive growth of algal cells can reduce light penetration, i.e., the growth process may be self limiting.

Nutrients

Algae need certain essential nutrients to build biomass. To sustain growth of new cells there needs to be a continuously available supply of carbon, nitrogen, and phosphorus, for example. This can be from exogenous sources, e.g., waste water discharges to the lake, or it can be supplied by recycling of nutrients through the complex ecosystem of producers, consumers, and decomposers, as illustrated schematically in Figure 1.

If any essential nutrient is deficient in the system, the growth rate, i.e., the rate of production of new biomass, may be regulated to conform to the available rate of supply, even though other nutrients may be present in abundance. Thus, an ecosystem may be characterized as "nitrogen limiting," indicating that growth can be controlled by regulating this critical nutrient. However, it may come to pass that as nitrogen is added to the system, a point will be reached where phosphorus or carbon supplies will govern, and a new growth regulator takes over. Actually, there may be several regulators of growth operative simultaneously and varying in control with time, place, and other environmental conditions. Such complex processes are difficult to describe mathematically for the purposes of ecosystem modeling, but empirical relationships have been developed that give a reasonable account of the effects of growth limiting factors.[5,6]

Temperature

All biological processes are temperature sensitive. At temperature extremes, either high or low, they may virtually cease. At intermediate levels they may proceed at maximal rates, the optimum rate for a particular biological process depending on the biota. In natural unstressed environments biota tend to be better adapted by natural selection processes to the range of temperatures on the low side of the maximum. Hence, extremes of high temperatures tend to impose greater stresses, perhaps ultimately leading to the demise of the ecosystem. Fortunately, the large spatial variability of temperatures in lake systems and the heat exchange processes between water and air mitigate temperature extremes that are likely to cause ecosystem collapse.

Temperature effects on the rates of biological process are generally well known from experience. Likewise, techniques for predicting temperature changes in lake systems are fairly well developed. Hence, the effects of temperature on the lake ecosystem can be incorporated in the ecologic model in a straightforward manner.

Toxicity

Most naturally occurring substances are toxic to living organisms at some concentration, but at lower levels they may actually be biostimulatory. Thus, there may be a threshold range over which the organism may function at near optimum levels, at least without inhibition of essential physiological processes. Such thresholds are known for certain compounds and species of organisms under controlled laboratory conditions although little is known as yet about the complex interactions that take place in natural environments with real ecosystems.

MODEL DEVELOPMENT

The development of a lake ecologic model proceeds logically through a succession of steps, more or less as follows:

1. Statement of goals and objectives.
2. Conceptual representation of the prototype.
3. Functional representation in mathematical form of hydrologic, water quality, and ecologic processes.
4. Computational representation in programming language for simulation on the digital computer.
5. Calibration of model against performance of prototype.
6. Verification of model's predictive capability.
7. Sensitivity testing of model's performance.
8. Documentation and preparation of user manuals.
9. Application to prototype cases.

The nature of each of these steps and their interrelationships has been described in detail elsewhere.[6] It may suffice for present purposes to summarize briefly a few of the more salient considerations.

GOALS AND OBJECTIVES

Questions of who is to use the model and for what purpose are primary considerations in model development. The academic may use the model as a vehicle of education and instruction. The scientist may see it as a means for comprehending the complex interrelationship of processes and systems and for defining areas for future research. The planner-decisionmaker may wish to use it as a means for evaluating alternatives.

In each instance, the requirements of reality with respect to the prototype are different. These, in turn, determine the temporal and spatial scales to be used, the data required, and sometimes even the computational methods employed. Accordingly, the time of development and cost are fixed by the degree of realism desired.

It must be recognized that despite the obvious tradeoff between realism and cost, there are practical limits of existing knowledge and technology that may preclude carrying development beyond certain limits of detail and sophistication. Often a simple model, wisely used, is much superior to an elegant model inexpertly applied. After all, the model is not a substitute for judgment, only a means to enhance it if that capability already exists.

CONCEPTUAL AND FUNCTIONAL REPRESENTATION

Conceptual representation of the prototype entails determination of the spatial and temporal scales at which the model will be constructed. In a deep lake or impoundment that experiences stratification it has been found by experience that the water body may be represented spatially as a series of horizontal lamina, i.e., slices, of equal thickness. These are arranged as a "system" along a vertical axis, as illustrated in Figure 2, a geometric representation of a stratified reservoir.

Within each control volume the properties of the water mass are considered uniform over some time interval appropriate to the rate processes being simulated. In the case of ecologic processes the time interval may be as little as one hour, although it is often convenient to use one day time steps.

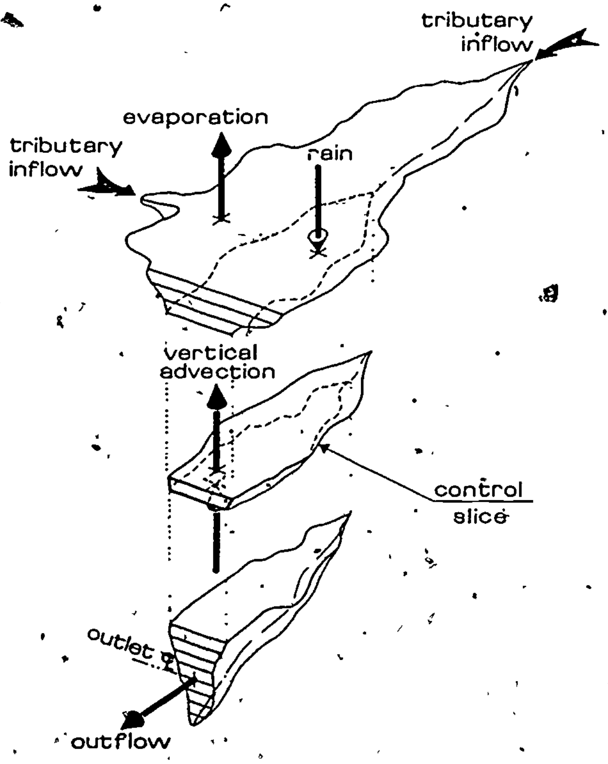


FIGURE 2.—Geometric representation of a stratified reservoir.

Formulation of the model entails identification of all pertinent quantities and processes and the parameters and coefficients that characterize them. One may gain some perspective of these for the lake ecologic model by inspection of idealized ecologic relationships depicted in Figure 1. In the upper sketch the various ecologic interactions are illustrated in the customary pictorialization of the aquatic biologist. The trophic levels identified include primary producers, both algae and rooted aquatic plants, zooplankton, pelagic and rough fishes, benthic animals, and bacteria (decomposers). Processes implied, in addition to advection and diffusion associated with the hydrodynamic behavior of the lake, are photosynthesis, growth, respiration, mortality, predation, decomposition, reaeration, oxidation, and sedimentation. Exogenous inputs to the system include sunlight, oxygen and carbon dioxide, sediment, and nutrients.

In the lower sketch the ecosystem is conceptualized in the style adopted by H. T. Odum[4] as a network of compartments (labeled P_1, P_2, Z, F, et cetera) joined by energy flow pathways. Following roughly the same spatial orientation depicted in the upper sketch, this schematic representation shows, by the direction of the arrows on the energy pathways, the flow of energy upward from primary producers (P_1 and P_2) through a succession of consumers (Z, F_1 and F_2), to ultimate harvest (H) by man. Within the system there is passive storage of certain constituents (oxygen, detritus, sediment, and nutrients, represented by the symbols O_1, O_2, D, S, N_1, and N_2 respectively). Changes in storage occur as these quantities are supplied (e.g., photosynthetic production of oxygen) or consumed by biota (e.g., grazing of detritus by zooplankton). Sediment is seen to accumulate on the lake bottom (S), providing food for benthic animals (B). These, in turn (with the aid of bacteria), return nutrients (N_2) to the aquatic system. Benthic animals are food for rough fish (F_2) that in turn may be harvested. It is noted that certain life processes are regulated by the availability of food (basic nutrients or biomass) and environmental factors like heat, light, and toxicity.

COMPUTATIONAL REPRESENTATION

This activity involves conversion of the model formulation into a computer program that permits simulation on the computer.

CALIBRATION, VERIFICATION AND SENSITIVITY TESTING

These activities are preparatory to model application. They are intended to establish the reliability of the model as a representation of the prototype, using data derived by direct observations of the real system.

Calibration entails adjustment of the model until it simulates prototype performance within some preset limits of reliability.

Verification involves checking model performance against the prototype without prior knowledge, i.e., predicting prototype behavior.

Sensitivity testing entails determining the reliability of the model under variable conditions of input data, levels of coefficients, spatial and temporal scales, et cetera.

DOCUMENTATION

This important step involves careful specification of the computer program and user instructions so that others may use the model.

APPLICATION

Application of the model is a continuing activity, involving simulation of prototype behavior for the purposes of evaluation of alternatives. It is best illustrated for our purposes here by discussion of an actual case study, that of Lake Washington.

LAKE WASHINGTON CASE STUDY

LAKE WASHINGTON ECOLOGIC MODEL

The concepts described above have been translated into a working ecologic model adaptable to a wide variety of aquatic systems, including stratified lakes. The first application of the model to a limnological system, Lake Washington, was performed as a part of testing during the development program sponsored by the Office of Water Resources Research (OWRR). The model was structured according to the concepts illustrated in Figures 1 and 2 using the Deep Reservoir Temperature Model developed previously by Water Resources Engineers, Inc.,[6] as a basic building block. In essence, the model in this form is one-dimensional, describing the temporal distribution of all water quality and ecologic parameters over the annual cycle and along the vertical axis.

Water quality and ecologic parameters included in the Lake Washington Ecologic Model are as follows:

Abiotic Substances and Physical-Chemical Parameters
- Nitrogen as
  - ammonia
  - nitrite
  - nitrate
- Phosphorus as phosphate
- Carbon dioxide
- Oxygen
- Total dissolved solids
- Temperature
- Alkalinity
- pH
- Sediment
- Detritus

Biota and Biological Parameters
- Biochemical oxygen demand (BOD)
- Coliform bacteria
- Phytoplankton as
  - large green algae
  - small green algae
- Zooplankton
- Nekton as
  - coldwater pelagic fishes
  - warmwater pelagic fishes
  - demersal (bottom) fishes
- Benthic animals

SELECTION OF CASE STUDY

Among a number of candidates for testing of the model concepts developed in the OWRR project, Lake Washington proved to be an outstanding choice for two reasons. First was the lake's unique experience over several decades, during which it was subjected to a wide range of pollutional stress. In the late 1950's and early 60's, the lake reached an advanced state of nutrient enrichment due primarily to direct discharges of treated wastewaters, coupled with periodic overflows from Seattle's combined sewer system. During the summer months until about 1965, algal blooms were experienced frequently at levels in the visible range. In the early 60's there was increasing evidence of impending disaster to aquatic life; dissolved oxygen levels in the hypolimnion dropped well below the levels required to sustain fish life and a steady downward trend was observed in each succeeding year.

In 1965, however, Seattle's METRO went into operation, collecting wastewater discharges and diverting them to Puget Sound. At about this same time, steps were initiated to minimize combined sewer overflows, thus reducing accidental enrichment of the lake. The effect on the lake was dramatic; in the following year peak levels of algae production dropped so that no blooms in the visible range were recorded. An obvious improvement in water quality was registered throughout the lake, particularly in reductions in the levels of nutrients available to support algal cell synthesis.

Perhaps equally important in choosing Lake Washington as a test case was the existence of an excellent body of field data, collected by W. T. Edmondson and his associates of the University of Washington. These data, including the primary nutrients, temperature, dissolved oxygen and chlorophyll concentrations, provided the basis for comparing model and prototype performance, i.e., evaluating the predictive capability of the model and calibrating it to prototype conditions. Time and space do not permit an exhaustive discussion of the many comparisons that were made; however, a few examples may serve to illustrate the model's performance in this initial application.

Figure 3 illustrates the annual cycle of dissolved oxygen distribution in the lake for hydrologic and waste discharge conditions corresponding to the period 1962 63, just prior to wastewater diversion by METRO. While there are local differences between the simulated and observed distribution of dissolved oxygen, the general pattern of progressive decline seems to be well described by the model; especially deep in the impoundment where oxygen resources are noted to drop steadily over the year to below 4 mg/l by late fall. Apparently, the model predicted a greater degree of stratification than occurred in the prototype, as evidenced by the somewhat lower D.O. levels calculated for the middle range of depth. This is borne out by a comparison of temperature distributions as well. No attempt was made in this preliminary study to calibrate the model to the field data, although if this had been done, closer agreement could surely have been obtained.

Of special interest, of course, is the temporal variation in algal biomass in the epilimnion of the lake during the period of nutrient enrichment. Figure 4 is illustrative of the annual cycle of algal biomass in the upper strata of the lake as simulated by the model and observed in the prototype. The solid line represents the model prediction of algal biomass for predischarge conditions of the 1962-63 period. It may be compared with the chlorophyll-a concentrations observed by Edmondson for the 1961-63 period.

It is noted that there is fair agreement between observed and simulated conditions during the early part of the year, through the peak bloom in mid-

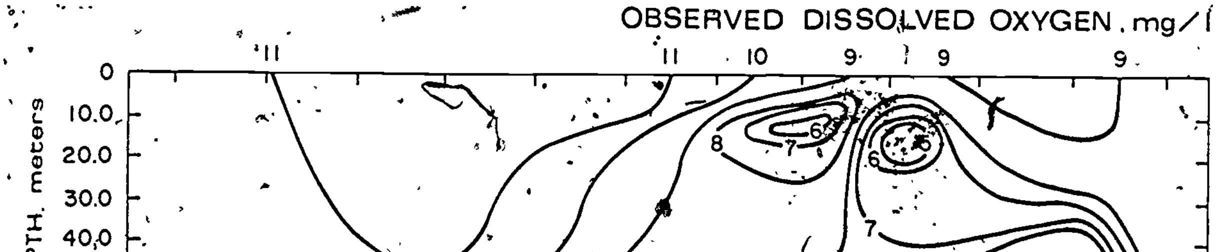


FIGURE 3. — Observed and simulated dissolved oxygen. Lake Washington. prediversion conditions.

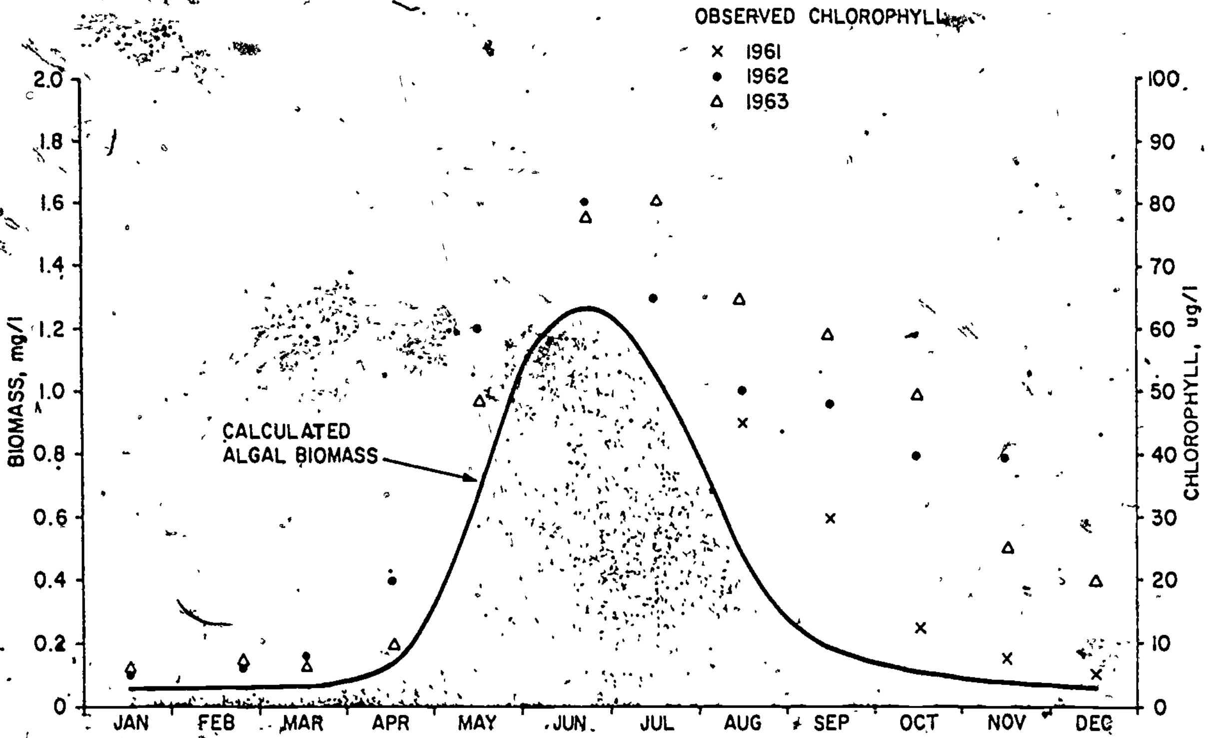


FIGURE 4.—Annual variation of simulated algal biomass and observed chlorophyll-*a* in surface strata, Lake Washington, prediversion conditions.

summer. The low concentrations sustained in the first quarter of the year are followed fairly closely, as is the abrupt growth of algae in April and May as the lake warms and stratifies. The peak values appear to be of the correct magnitude generally although no attempt was made in this preliminary study to calibrate the model to the actual data.

Figure 5 shows the distribution of algal biomass in the upper 60 meters of water column over the full annual cycle. Clearly evident is the high primary productivity of the lake's upper strata in the warmer summer months. The typical fall overturn and the attendant drop in algal biomass is also apparent. These results of model simulation of the lake's behavior are corroborated by Edmondson's chlorophyll-*a* data depicted in the upper portion of the figure.

An illustration of ecologic succession is seen in the temporal relationships between two groups of algae and zooplankton presented in Figure 6. The small green algae (the upper curve in the figure) that grow rapidly at low light intensity are depicted as growing rapidly early in the year, reaching peak biomass levels in late May. The slower growing large green algae follow, taking what is left of available food. They peak later and at somewhat lower levels. The zooplankton, feeding on both algal groups, grow slowly and reach biomass levels about 5 to 10 percent of that of total phytoplankton. They peak in mid-August, 1.5 to 2 months later than the algae. This pattern has been corroborated generally in Lake Washington by direct observation although data on zooplankton standing crops are meager.

EVALUATION OF ALTERNATIVES

As an illustration of the model's utility as a planning tool, a comparison was made between pre- and post-diversion conditions as predicted by simulation of representative annual cycles. In the upper portion of Figure 7, the attenuation in the algal biomass curve resulting from diversion of wastewaters from the system is clearly demonstrated. The results depicted, although they represent average "before" and "after" conditions hydrologically and from the waste disposal point of view, are in agreement with the pattern of chlorophyll *a* distribution as noted by Edmondson. Both the depression of the peak and its shift in time are characteristic of a strong trend toward recovery of the lake from its previous eutrophic condition.

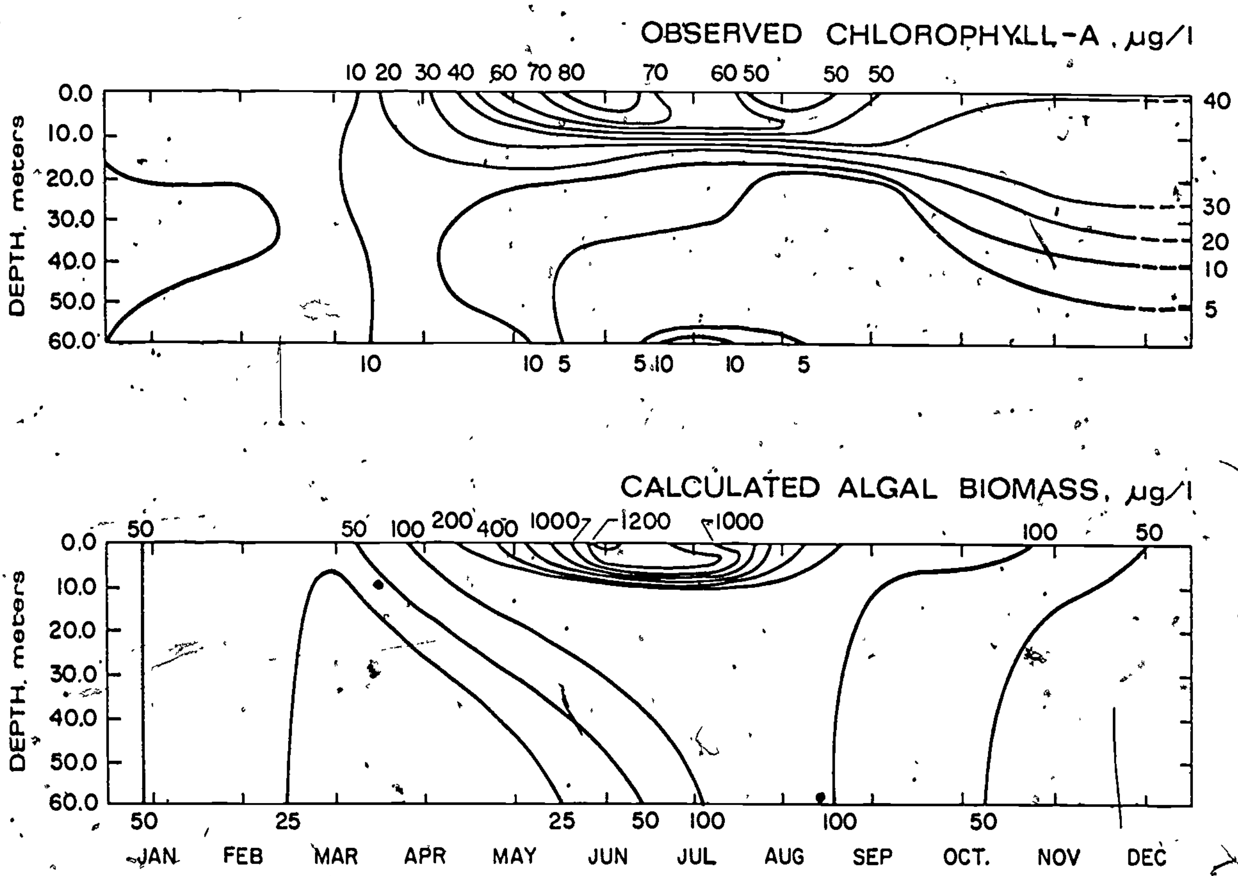


FIGURE 5.—Simulated algal biomass and observed chlorophyll-a, variation with depth and time, Lake Washington, prediversion conditions.

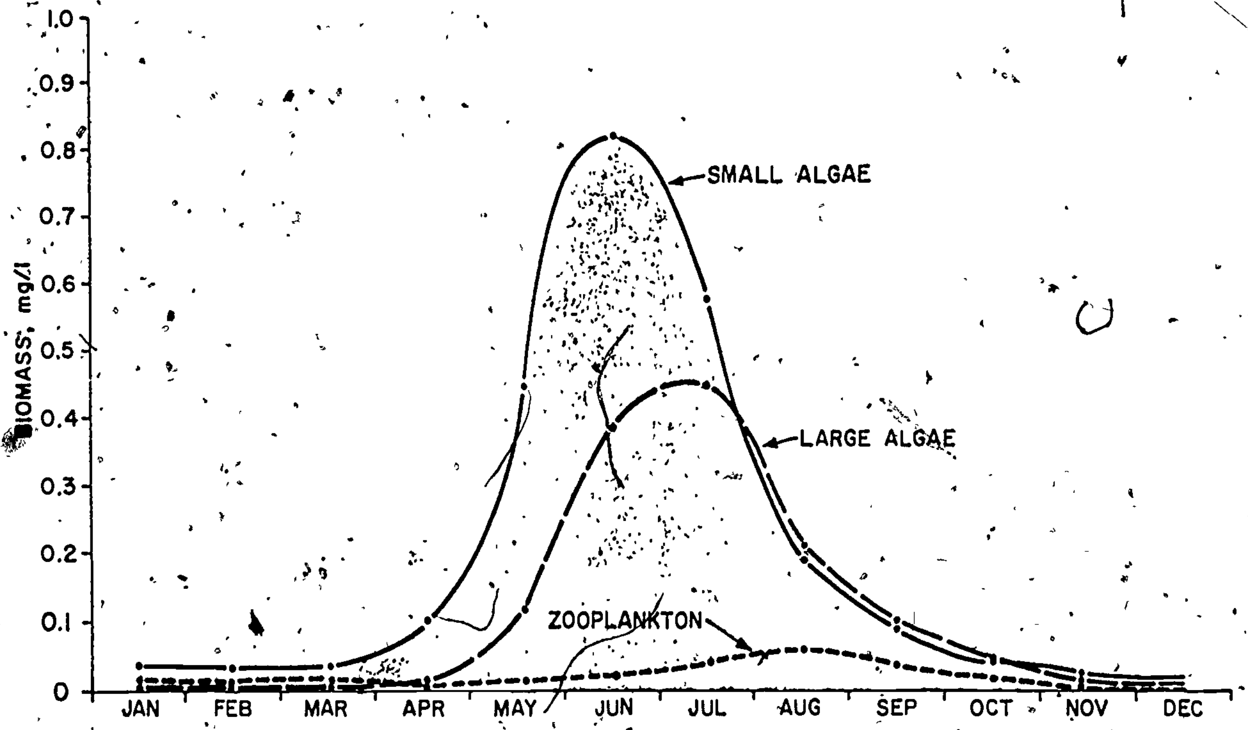
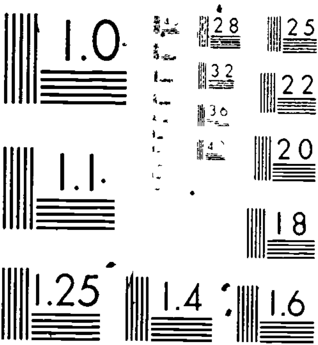


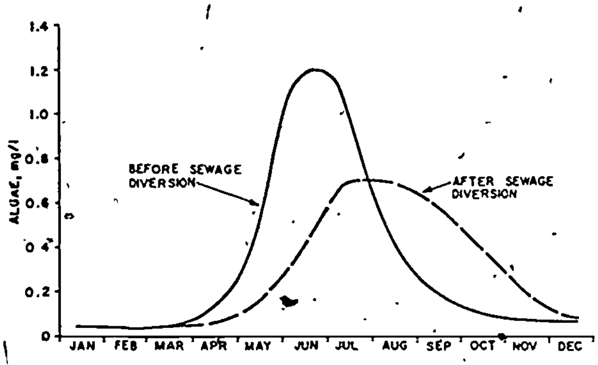
FIGURE 6.—Simulated ecological successions, Lake Washington prediversion conditions.



MICROCOPY RESOLUTION TEST CHART

[illegible]

In the lower portion of Figure 7 the annual changes in dissolved oxygen concentrations near the lake bottom for the same two cases are illustrated. It is observed that despite wastewater diversion the downward trend of oxygen resources deep in the lake is little changed. This model result is also in agreement with the prototype's behavior and illustrates the dominant oxygen demand of the benthos, a factor that is not dramatically altered by diversion of nutrients from the lake.



SURFACE ALGAL DENSITY

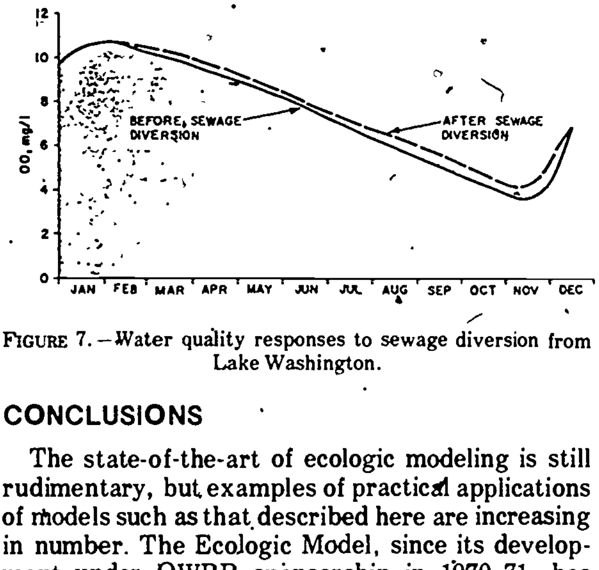


FIGURE 7.—Water quality responses to sewage diversion from Lake Washington.

CONCLUSIONS

The state-of-the-art of ecologic modeling is still rudimentary, but examples of practical applications of models such as that described here are increasing in number. The Ecologic Model, since its development under OWRR sponsorship in 1970-71, has been applied in a variety of environmental planning situations. Recently, under joint sponsorship of the OWRR and the Environmental Protection Agency the model was adapted to Puget Sound and to six subsystems of this complex marine environment.[7] It has been extended in its capability in further applications on Lake Washington and to a series of artificial impoundments.[8,9,10] The basic concepts of the model have also been incorporated in models previously developed for vertically mixed estuaries along the Pacific and gulf coasts and to coastal zones in New England and California.

Conceptually, models of aquatic ecosystems that incorporate water quality interactions can be adapted to a wide variety of planning situations, including those of lakes and manmade impoundments. Basic formulations of the energy or mass conservation type can be developed for abiotic substances. These appear to be reasonably defensible in light of the existing body of knowledge on the behavior of aquatic biota. Simulations of ecosystem behavior using such models appear to agree quite well with prototype observations.

If there are limitations in the use of such models for planning purposes, they are probably most identified with the lack of reliable data from the prototype that will serve both to calibrate and test the model and to instruct the modeler in how to improve this potentially useful tool. As experience is gained and ecologic models are tested and revised, confidence in their capabilities and awareness of their limitations are sure to grow. They are destined to figure prominently in future environmental planning and decisionmaking.

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DISCUSSION

Comment: Since 1916 we have been trying to get drinking water standards that are acceptable for potable water, that is, something you can put in a container, see, and observe. Again, we haven't got any uniformity there. The uniformity, or the lack of uniformity, rather, comes from not being in constancy one State with the other. How in the world are we going to train, and where are we going to get necessary professional-type people to make these studies that can say this is up to standards and this is how it can be maintained.

The point was made earlier that technicians can do this; I submit they can. But, when something overwhelms the system and turns off the model and goes beyond the belljar, then you are in deep trouble. You don't have time in a major facility system to wonder what happened, you have to correct the situation. Where are these people coming from? The engineer who graduates this June will only be one-half of the people who will be needed for other types of engineering.

Mr. Orlob: I'm not sure I have an answer for that. Those that have associations with academic institutions are trying to do something about that, but we are suffering the consequences of a lag in training of professionals that was imposed on us about 10 years back when it was much more glamorous to be involved in electronics or space exploration. I think that we are now suffering from lack of support for training and research. We in the universities are desperately in need of that support from governmental agencies.

We need support of EPA, for example, in the programs that will bring about required training for young engineers, chemists, and biologists with environmental orientation. Incidentally, we have such a tremendous interest on the part of students at the University of California with which I am affiliated, and we can't handle them all. We don't have opportunities for them that are competitive with those of other fields in which there is money available.

One of the important parts of our support capabilities in the universities has been the training grants program, provided for a considerable time by EPA and its predecessors, but which is being cut off in the next year or so. This is a great loss to academic institutions in attracting qualified students to environmental programs.

The problems we are dealing with, I think, are more complex than they ever were; they require training of people with depth of understanding and sensitivity for environmental matters, even though young and as yet unskilled in the application of new technology.

Comment: I was intrigued by your comment that the goals of management objectives are often inadequately defined before modeling gets under way. I wonder if you would like to reemphasize that point and perhaps touch on what recommendations you would like to make for research and development in modeling.

Mr. Orlob: I think there have been some good steps taken to correct that situation. One of these was made by EPA recently in its River Basin Modeling Program.

Up to a certain point in time, most of the models that were developed, of the type described in my talk, were developed under special research contracts. That is, they were discrete model development projects not related to planning. This phase of development was great; I participated in it. But, a question arose as to whether these models would ever be brought to bear on real problems. During this period there was a proliferation of models, far beyond our real needs.

Probably about 90 percent of those produced are really not worth anything to environmental planners and decisionmakers. EPA undertook, a year or two ago, to take those models that were best documented in the literature and, although they had some deficiencies, to apply them to real river basin planning situations, to prepare them for use by planners, to document them properly, to calibrate and verify them. This was done for some 25 river basins and a dozen or so models. I believe in some cases the effort was a considerable success, because these models are now being used as tools in planning in a number of States, and at the State level. I'm sure you will find some of these models being used, for example, in 208 planning studies that are now getting underway in many States.

Nevertheless, I do think there is still a need to continue some basic development, extending our understanding in fundamental behavior of the aquatic environment. There is much that we need to know and to do to make our models.

EPA and others who are involved in action programs want to see these tools tuned a bit and then applied. The greatest benefit that we can realize now in the modeling state-of-the-art comes from actual application. Through applications model users will learn limitations and deficiencies of such tools and techniques. I believe we have enough models now; we need merely to understand them a little better.

A number of our earlier models were developed in the context of actual planning studies and served some useful purposes there. Estuarine models have been notable examples; they were quite widely used and still are being beneficially applied in planning situations. I think such models are rather well developed. Perhaps ecologic models of lake and estuarine environmental systems are not yet as advanced. I would like to see a continuing effort on a modest scale in research related to modeling. More emphasis should be placed on application, checking, and verifying of existing models.

One last comment: it seems to me that there is a need for a sort of national register of modeling capabilities. At present, it is exceedingly difficult to identify sources of operational models and computer programs. Most of this technology is widely dispersed and not at all coordinated as to specifications, quality, and availability. A national register, such as I suggest, could fill a critical need and bring order to the modeling art.

THE WATERSHED AS A MANAGEMENT CONCEPT

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The management of a region on the basis of its hydrological system is as old as man's culture. Dams were built on mountain slopes (the rice paddies in Java) and in rivers to retain the water for human and irrigation uses. Later, navigation requirements became economically of importance and water level controls were built. Dams, locks, and dredging operations were undertaken to cater to the need of this particular water use. Famous examples are the Rideau system in Ontario with its 47 locks, and the 360-mile long Erie canal with its 82 locks; both built between 110-140 years ago when navigation was a predominant water use.

A further significant step in water use development came with the advent of hydroelectric power. The significance of this water use is particularly great in Canada (82 percent of total electricity production). In the U.S. it accounts for 10 percent of the national power production.[1] The provision for all these water requirements in the form of reservoirs, aquaducts, locks, and dams created, in general, fine examples of contemporary engineering skills.

Yet, it is only in the last decade that we have come to experience that all is not well—in the course of our dealings with water, we have gravely neglected the multiplicity of its uses, of its features, and the ubiquity of its nature.

This seminar attempts to shed light on the variety of aspects involved in the phrase "the integrity of water." I would like to contribute to this discussion by focusing on water uses and their functions and relationships.

Figure 1 shows the three major categories of the functions of water: the biological, the environmental, and the economic uses. The incomparability is striking. In human biological use we work in milligrams or litres; for industrial waters, in billions of gallons; and for power uses, in acre-feet. For environmental use, a quantitative expression is often not relevant.

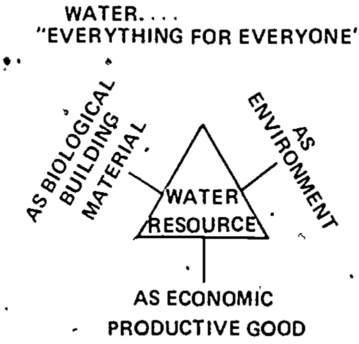

FIGURE 1

Water is part of the hydrological cycle on a worldwide scale, and it is part of animal metabolism. It is both outer environment and inner environment, at the same time. Being thoroughly confused by this complexity, mankind until recently was not quite able to deal with water in a fashion consistent with his dealings with the other materials and commodities. The ownership concept, as applicable (Figure 2) to nearly all human products and most natural resources, was only applicable in a half-hearted way. Although common law recognized Riparian Rights, they never attained such a clear, decisive status as, for example, property rights. In fact, the broad intent of Riparian Rights appears to be impracticable. The market mechanism did not work for water either; this was, of course, partially the consequence of a lack of definition of ownership—the fact that water is a common property resource.

The variety of and the competition for simultaneous uses—(fishing, navigation, and sewage dilution for example), and further, the occurrence of sequential uses (for example, the chain: mountain brook - drinking water - sewage - lake - drinking water)—were not regulated by the market mechanisms. There is no generally and conveniently accepted way of paying the upstream user for not polluting. Similarly, the upstream user cannot pay the downstream user for the privilege of polluting.

In history, the disasters caused by sequential water uses have perhaps dominated the field of man's communicative diseases until the use of chlorine in water treatment was introduced. With this

THE SOCIO-ECONOMIC ASPECTS
OF WATER MANAGEMENT

- –OWNERSHIP: WHO HAS RIGHTS?
- –SHORES & RIVER BANKS: WHAT RIGHTS?
- –CONFLICTING WATER USES:
  - SIMULTANEOUS
  - SEQUENTIAL
  - WIDELY VARYING PURPOSES
    - IN SITU
    - WITHDRAWALS
    - DILUTION OF WASTE

∴ AND THE "MARKET PLACE" HAS NO MEANS OF RESOLVING THE CONFLICTS.

FIGURE 2

step, it looked as if a comfortable plateau was reached. But it was soon learned that this sanitary achievement only gave a temporary relief. Our understanding of the water system was still far from complete.

In close range, new problems rang for attention: industrial waste, eutrophication, toxic substances, radioactive wastes, thermal wastes, introduction of alien fish species, drop in fish harvests, contaminated fish products, oil spills, et cetera.

Definite conclusions arise from this list of ills:

1. All are caused directly or indirectly by man's activities.
2. Although all problems originate with man, each is part of a different man-environment relationship.
3. Damages were incurred by the forest and flora, by animal, wildlife, and fish populations, as well as by humans. These damages, of course, varied from case to case and were seldom limited to one category only.

It becomes apparent that water management is not possible without accounting heavily for man's activities, and further, we have come to see the problems of water not in the narrow sense—i.e., the water within the boundaries of shores and river banks—but in the organic totality of the watershed.

Water in the watershed forms an organic totality with the soils and vegetation in that watershed, and with the entire animal, fish, and human populations including all their activities in that basin, and, last but not least, the climatic conditions of the basin. The watershed is, in fact, a big pipe: in comes rainwater, clean or loaded with chemicals; out flows a liquid, sometimes loaded with chemicals, sometimes carrying excessive heat and perhaps even radioactive particles. On its journey through this big pipe, this water has been used, over and over—bringing into each process whatever was left of the previous processes, cleaning up somewhat by assimilation processes in between.

This unique and complex set of relationships and interdependencies is The Watershed System. Anyone who attempts to manage such a system cannot manage it in ignorance of the fact that, in such a system, Everything is Related to Everything Else.* For the manager not only needs to know how the main system behaves, he should be well aware of the behavior of the many subsystems included within the main system. I have attempted (Figure 3) to list the main systems and some major subsystems playing their part in the watershed.

The use of systems analysis can bring order to this chaos of complexities by providing mechanisms for systematic searching for interrelationships and for building conceptual frameworks wherein the nature of these relationships can be expressed, studied, quantified, and tested. With systems analysis approaches one can study the whole without losing touch with the parts!

In the 50's and 60's we made the step from single purpose development objectives for water resources to multiple purpose development. In fact, this only meant that instead of one, two or three purposes were pursued. But this is far from a comprehensive approach. Therefore, the latter concept

THE ELEMENTS OF THE WATER SHED

NATURAL SYSTEMS

- –GEOLOGY, HYDROGEOLOGY
- –TOPOGRAPHY
- –PHYSIOGRAPHY
- –CLIMATE
- –WATER RESOURCES
  - PHYSICAL, CHEMICAL, BIOLOGICAL
  - LIMNOLOGY
  - FISH POPULATION
  - HYDROLOGY
  - SEDIMENTATION
- –LAND RESOURCES
  - SOILS & VEGETATION
  - WILDLIFE
  - EROSION

SOCIAL SYSTEMS

- –DEMOGRAPHIC & SETTLEMENT PATTERNS
- –ECONOMIC CONDITIONS & ACTIVITIES
  - AGRICULTURE
  - MINING
  - MANUFACTURING
  - SERVICE INDUSTRIES
- –LAND USES
- –RECREATION
- –INSTITUTIONAL & LEGAL STRUCTURES

FIGURE 3

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*Credit for this expression goes to Dr. O. M. Solandt, former Chairman of the Science Council of Canada.

now needs further deepening to become eventually what I would coin as a "harmonic basin development concept." This is considered to be a state in which all aspects and purposes have developed, or are developing to an optimum individual condition with a minimum damage to other aspects. Maximizing of all potentials, along with minimizing of all damages—the aim is the attainment of a delicate balance. Such a condition can only be obtained by careful planning, and careful planning in turn can only be successful if it is based on knowledge and insight into the problems.

When one attempts to undertake this exercise it becomes immediately and painfully apparent how much we do not know, despite the great number of scientific achievements. Much of our knowledge—of necessity—has been formed in separate disciplines; the linkages have now to be formed.

The assumptions in one disciplinary field are often the subject of study in other disciplines. What I mean is that any one problem-parameter is generally expressed in terms of one or more non-problem-parameters; at least in the terms of a particular scientist or a particular discipline. However, non-problem-parameters in most cases are problem-parameters for other scientists or for other disciplines. This condition brings us to the heart of the problem of watershed management. It is a highly multidisciplinary task. What was taken for granted in single purpose resource development, and reasonably acceptable in multipurpose development, has now lost the basis for its validity nearly entirely for the harmonic basin development concept.

For example, a so-called multipurpose water management plan might have aimed at resolving conflicts between hydropower, navigation, and drinking water needs. But this limited set of considerations is no longer acceptable.

The "water-quality-man" thought before in terms of concentrations of contaminants in the water. Once one had managed the analytical techniques, it was then a simple matter of establishing some criteria based on the known toxicity of the substance. Now we know that one cannot look at concentrations in isolation. Biological amplification can increase such concentrations many times if suitable biological chains—of predator and prey—exist.

The forestry industry needs budworm control programs as a part of our economic livelihood. But such a program—using pesticides—immediately affects the health of fish and wildlife and perhaps, indirectly, the well-being of the basin's human population. The pathways of contaminants are often not clear. That some of this type of waste comes back and affects the health of the population is unavoidable. The costs of such effects are largely unknown at the present, but they might be important enough to cause economic concern in addition to social concern.

Much, if not all of this, depends—as the conventional wisdom has it—on the people's choice (Figure 4). But reading the people's choice is not an easy or simple matter. Sociologists have not been able to map out clearly the people's perception of the water resource, and their attitudes based on such perceptions. Again, the multiplicity of water uses makes it extremely difficult to map out clear preferences of the population. This is even a much graver problem if we realize that water has also a strong locational feature, a strong regional aspect.

Because of the absence of the market mechanism, as it is available for commodities, the channels of communication of the population for the purpose of formulating decisions and the feedback of such decisions are extremely unclear. Nevertheless, as we all can observe, they are, in all aspects, real.

This obvious vacuum in the system has been filled by the governments (Figure 5). They are charged with the difficult task of equally distributing benefits, and disadvantages, of the water resource to their populations.

I have been listing all the negative points, all the problems, and the lack of sufficient understanding of social, chemical, physical, and biological processes. It is now time to come to the more positive points; to discuss the ways open toward achieving a harmonious watershed development. The critical function in this process is "conflict resolution." This conflict resolution should take place in each of the hierarchically arranged strata of the watershed system. Then, the consequences of each choice in

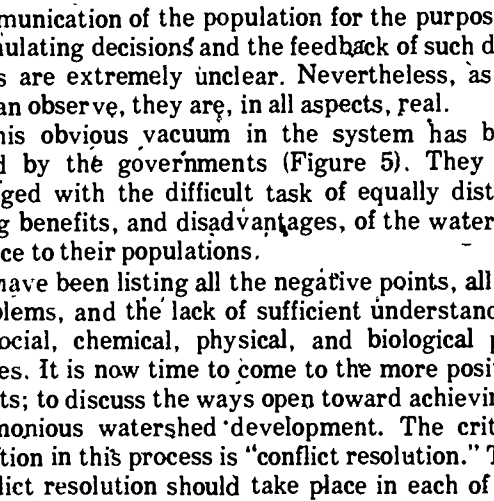

FIGURE 4

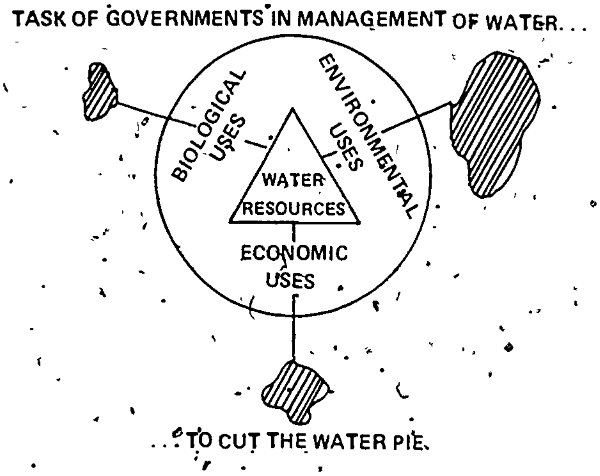

FIGURE 5

the conflict resolution process should be worked out to assess the various impacts resulting from these choices in the future. This latter phase is extremely important. History has shown us in so many fields and cases that the outcome of well-intended programs and policies turns sour in a number of years. This is no surprise to systems analysts, who are well aware of the fact that complex systems tend to behave counter-intuitively.

Conflict resolution balances interests against interests: health interests against economic welfare, wildlife against forestry, fish against fisheries, and so on. There is no clear common denominator for this balancing process, although many attempts have been made to use economic criteria as common standards. The fallacy of this thinking—as an omnibus solution—has become quite apparent. Research is active in this field but no comprehensive solution has been formed. Nevertheless work can continue even with less perfect tools.

The complexity of all the elements making up the behavior of a watershed system is too great to be synthesized within the minds of individuals. Computerized simulation models are the essential tools in this process. The model, like a huge accounting machine, keeps track of all the entries (parameters) in all their proper relations. Watersheds are not only complex, their reaction time, in some cases—as for example in the Great Lakes—is very slow (Figure 6). And such slowness requires a considerable policy lead time (Figure 7). Also, the cumulative nature of contaminants and the processes of biological amplification are long term effects. Of the social aspects, changes in attitudes of the population take place only very slowly, and economic adjustments in the basin are slow and often painful. Likewise, institutional adaptations, if they follow each other too quickly, often confuse the public and create feelings of instability. Social and environmental experimentation are beyond our capability, and certainly beyond responsible behavior if the consequences of such an experiment could be disastrous.

Simulation is then the only way out, and through simulation the cybernetic potentials can be tested for their usefulness, and their potential for translation into policies and programs. Conflicts can be resolved at each level of the system's hierarchy; the tradeoffs can become clear. The need for data—and applied research—follows from sensitivity analyses procedures. Hereby, the results over time are tested for their sensitivity to variations in key determinants of the system.

The watershed management concept, as I have described it so far, is now being used in various basins of the world although at different levels of sophistication. Some examples of well-established river basin management agencies are the Ruhr Area Genossenschaften in Germany; the River Basin Boards in Britain; the River Basin Commissions under the Water Resources Planning Act (1965) in the U.S.A. (such as the Great Lakes Basin Commission); and the basin studies set up through joint Provincial/Federal consultation under the Canada Water Act.

I will now dwell for a few moments on the joint basin studies in the Great Lakes to exemplify the application of the watershed concept as a management tool. Under the Canada-U.S.A. Water Quality Agreement of 1972, and under the auspices of the International Joint Commission, intensive study plans are being carried out to study (a) the pollution of the upper Great Lakes and (b) the pollution from land use activities in the Great Lakes. The broadness and the multi-disciplinary scope of study is unprecedented. Data and surveys range from space

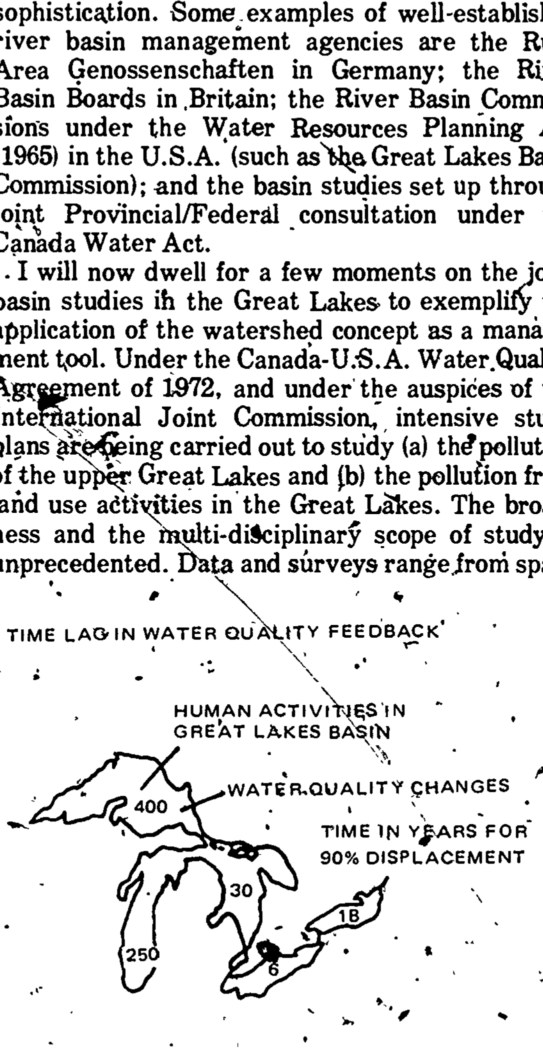

FIGURE 6

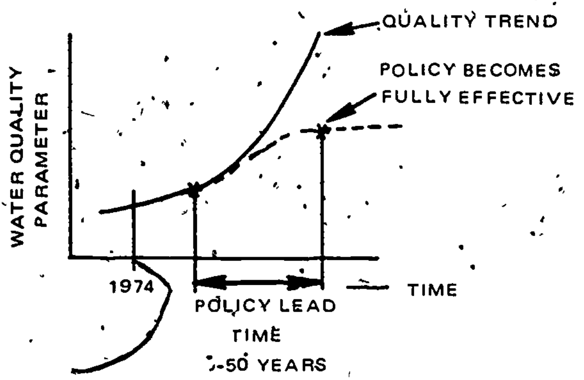

FIGURE 7

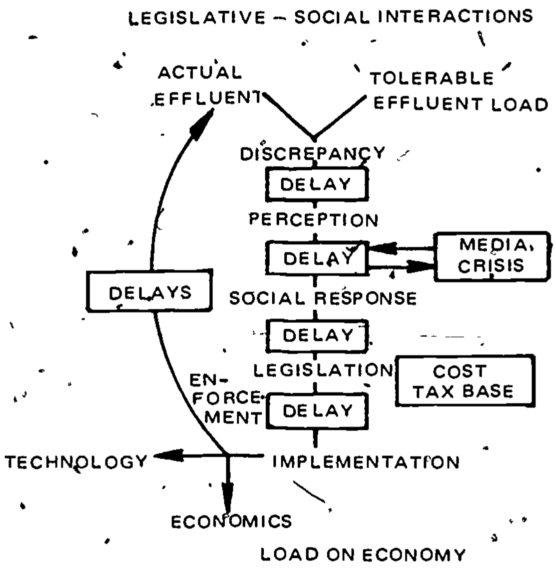

FIGURE 8

observations through the ERTS Satellite (Earth Resources Technology Satellite) to the electron microscope observations of asbestos fibers, and indepth social analysis.

On this broad scale, trends are being developed for a period of 50 years. Changes in technology, economic structure, population, and attitudes towards the limited resources of this planet, are being applied to the Great Lakes Basin Studies.

The increased desire of watershed inhabitants to have a direct input into watershed planning that may affect their quality of life and the values of their possessions has led to the formulation of various channels—different for different jurisdictions—for public participation in water planning and management. For decades we have planned through processes of simplification (of necessity!). Present technology allows us to go complex again; to take into account valuable details brought forward by public participation. This is expressed by the International Joint Commission Public Hearings Program.

Models for atmospheric loading of pollutants from industrial activities, for water quality, for socio-economic aspects, and for policy analysis, are all part of this huge effort in which the two countries, the basin States, and Ontario cooperate.

Other models are being developed at university research institutes. For instance, the Systems Research Center of Case Western Reserve University is developing a water management model as a tool for policy analysis. Figure 8 shows a compressed conceptual diagram illustrating the flow in a submodel for policy analysis. Canada Centre for Inland Waters has developed water quality models, hydrodynamic, physical, and biochemical models. The Center for Geographic Analysis of the Institute for Environmental Studies of the University of Wisconsin in Madison is working on a heuristic model of the Lake Superior Region, and York University, Toronto, is working on a Waste Loading Simulation Model for the Great Lakes. The schematic representation of this model in Figure 9 shows that the link with the physical models is still missing.

These are only a few factors in the field; outside the Great Lakes many other attempts are being made at modeling watersheds. This should not be considered as wasteful duplication. Because of the complexity of the matter, many viewpoints are possible, and although apparently contradictory, they often are not so in the context of the larger sys-

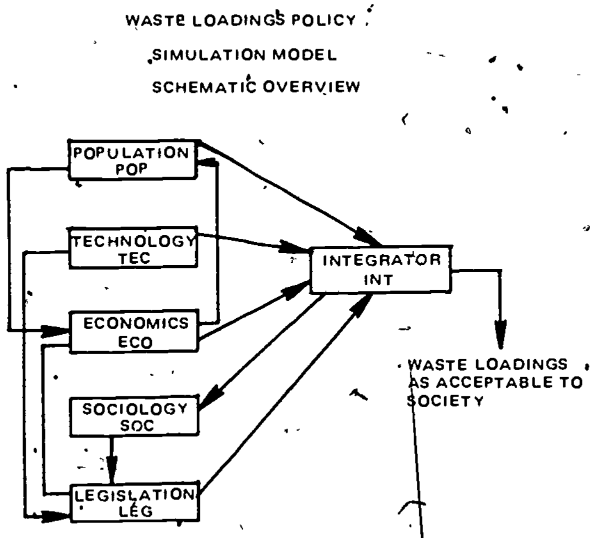

FIGURE 9

tems. Where the old disciplinary models describing the phenomena in each discipline were probably correct in their own way, they now seem to lose some of their neatness in the broader set of options provided by a comprehensive model, and one of the difficult tasks, which was only undertaken in recent years, is to bring these disciplinary models together into comprehensive basin models. The stage of developing linkages is still fairly primitive.

In conclusion, hydrologic engineers, limnologists, economists, fish biologists, toxicologists, and legal analysts have to come to terms at the peripheries of their various disciplines. And the problem of this is much more than a human or disciplinary one. It is in fact, a thrust forward to a higher level of comprehension. In this effort all inputs from different organizations are needed to obtain a really comprehensive understanding of the problems with a realistic accounting of all the possible factors.

The concept of the watershed has begun to lead us to an adaptation of our institutions to recognize socio-physical realities that cannot be neglected. This adaptation will further affect our public and private works design to include the integrity of water, not as a residual, but as an integral design specification.

INTEGRITY—
AN INTERPRETATION

THE STATES' VIEW

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State of California
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presented by
PORTER TOWNER
Chief Counsel

I appreciate the opportunity to participate in this Symposium and to present an interpretation of the States' view of the integrity of water.

Thus far, the program has dealt with integrity from a physical, chemical, and biological point of view. From the many interpretations presented, it can clearly be seen that integrity, like beauty, is in the eye of the beholder.

In spite of the wide variety of comments that have been made here, basically the presentations can be categorized as technical or scientific in nature. In this panel, we see the "political" view—in the broadest sense. And that is very broad indeed. Whether the approach is technical or political, however, each of us at this session interprets the integrity of water on the basis of our day-to-day relationships to water management or mismanagement.

I am aware of this personally because I am in transition. When this program was prepared, I was a member of a State regulatory body with responsibility for water quality and water rights. Last week I became the director of a State department charged with constructing and operating a major water project and carrying out water conservation and development planning.

In addition to the institutional structures that can influence interpretation of integrity, there are geographical factors as well. My native State is a land of contrasts. There are mighty mountain streams and vast areas of semi-desert. Unfortunately, we have located more than half our 20 million people on that water-short desert area.

From a water quality standpoint, we have used the ocean as our principal disposal receiving area for urban wastes. Yet, 85 percent of our water use is by agriculture, and its problems of waste disposal are vastly different than those of a primarily urban area. Further, most agricultural problems are located inland in fertile valleys which afford limited possibilities for disposal.

Having sufficiently warned you of my institutional and geographical biases, I would now like to offer my interpretation of the integrity of water. This interpretation, while necessarily drawn from my experiences, tries to consider the forest and not just the trees.

Historically, the control of water quality has been the primary responsibility of the States, and that is basically a sound system. Theoretically, the States should not be as susceptible to political and economic pressures as local government agencies traditionally have tended to be. Nor are the States as remote from specific areawide problems as the government on the Potomac.

Since 1972 the States' authority has been strengthened by the establishment of a National policy on water quality. The previous threats of some polluters to the States—"You're driving business away. We can't compete because others in the field will not have the same expenses you are forcing on us. We'll move out if you get tough!"—are no longer effective.

Even though the Federal Water Pollution Control Act Amendments of 1972—through the establishment of National goals and a relatively uniform level of pollution control—restrict the discretion of the States to some degree, immense authority and responsibility still remain. For example, the law gives the States the impetus to expand their regulatory authority through administration of the NPDES permit system. And there are many tasks left to accomplish, such as: regulation of discharges to ground waters, nonpoint pollution control, innovative planning, and designing institutional means for implementing plans.

Historically, the water allocation process, as represented by water rights administration in the western States, is also a State responsibility. Although here, too, there is a substantial Federal influence—through the activities of Federal construction agencies and Federal exercise of water rights—there is still much the States can do. Again, as an example, water rights administrators in the States can increasingly define the "public interest" not only in economic terms but also in a manner to recognize the myriad of noneconomic social values as well.

Thus, the States' role is potentially a large and important one—but one that is not easy to perform. The basic challenge is to reflect society's values and maintain the integrity of water at the same time. Conflicts are inevitable.

For example, preserving a free-flowing river in its original state is increasingly a goal of modern society. The use of river flow is in conflict with such an integrity of water, and yet the use of river flow is often a necessity.

There is a recognized need for reclamation of waste water but insufficient effort has been generated toward solving potential health problems which may restrict the beneficial uses to which such water may be put. In addition, traditional economics weigh heavily against the environmental benefits of wastewater reclamation, yet there is reluctance to face the need to price water in a manner which would induce conservation of the supplies.

Some groundwater basins are subject to severe overdraft, while others experience high water tables to the point that agricultural crops are threatened. In spite of this, there is often a lack of law and institutions which could protect these basins and often tremendous pressures are exerted against attempts to enact appropriate legislation.

There are problems of salt buildup in soils and this requires flushing—and a subsequent degradation in water quality.

In many areas there is a real controversy over whether power plants should be sited on the coast or inland. Both siting alternatives have their share of economic and environmental "tradeoffs."

There is continuing competition for water supplies between instream use for fisheries and recreation and consumptive use f[illegible]dustrial, agricultural, and domestic supplies.

Water use is also related to land use. In fact, there are those who would accomplish restrictive growth policy through limiting water supplies. However, the record to date is one of confusion and inconsistency.

I hope you are detecting a thread of continuity here: namely, the complexity of the problem of interpreting and maintaining integrity of water from the States' point of view. The States' responsibility to maintain the integrity of water must be worked into a total response to the needs of the public. In fact, the States' interest and the public interest should really be one and the same.

I believe the future holds the opportunity for aggressive, innovative and bold actions by the States, through which they can preserve their role in maintaining the integrity of water. There are several ways to make this possible.

The first method is to strengthen the environmental impact process. The impact statement is most valuable in assuring the thorough analysis of alternatives. It cannot just be a tool with which to justify a project already committed or to explain a decision already made. The environmental impact process must be made part of the planning process itself. And we must fully, and at an early stage, involve the public in the environmental impact process.

I would point out, parenthetically, that in spite of the usefulness of the impact process—as demonstrated at the Federal level and by several States—less than half of the States employ such procedures.

Another means of maintaining integrity is through innovative problem-solving. The States need to be willing to explore the use of solar energy, geothermal resources, wastewater reclamation, groundwater management, and, most importantly, water conservation practices. In addition, many more imaginative and innovative changes in institutional management and applicable legal doctrines will be necessary if the States are to maintain the integrity of water.

Finally, a more sophisticated approach to coordinated statewide resources planning must be taken. We need to set statewide goals—goals which are not narrow and oriented to the special interests of single-purpose governmental agencies, but which best represent the truth and integrity of water in a society determined to eliminate wastes with efficiency and with the public interest foremost in mind.

This is not as easy as it sounds. Often "people in high places" have been educated in certain fields and are reluctant, or in some cases unable, to break out of traditional molds to consider true alternatives. To use an example not related to water, but which basically illustrates my point, consider the transportation planner. Traditionally, the planner started with the concept of the automobile, thus limiting the scope of possibilities to be considered.

We can now see the folly of statewide plans for freeways primarily based upon the philosophy of those who make their living by the mile. Likewise, we must view with suspicion statewide water plans which are produced by those whose philosophy is based upon the acre-foot, or for that matter, upon the discharge requirement alone. We need to view the whole and place within it the pieces—each in its proper position. We need to reeducate planners, not only by college courses in new concepts, but through receiving input into the planning process from other disciplines, including those associated with environmental protection.

We must recognize and institutionalize the obvious fact that water quality and quantity are inseparable. As strange as it seems, this is a fairly new concept and not reflected in the 1972 Amendments. Traditionally, in the western States the main problem occupying those concerned with water resources development and management has been quantity of water—just getting the water to the right place at the right time. In recent years, quality has become a key factor, something we can no longer take for granted.

In most States, including my own, we are still struggling to respond to changing obligations of the States. But meet them we must, or the States in this Nation will run the risk of abdicating their responsibilities. Neither can we afford to kick our problems upstairs instead of tackling them.

Above all, the States must not sink into bureaucratic inertia. Such an event is not an impossibility and it would truly be a tragedy. The noted critic Brooks Atkinson once wrote: "Bureaucracies are designed to perform public business. But as soon as a bureaucracy is established, it develops an autonomous spiritual life and comes to regard the public as its enemy."

Surely the States can avoid this pitfall, for the goals of our Federal environmental statutes and our own common sense tell us that, unless the integrity of water is maintained, our Nation cannot long survive. These goals are not yet universally accepted by those implementing efforts in the States—at least not in every place at all times. But the States and their local governmental subdivisions must strive for universal acceptance and implementation of these goals.

The integrity of water is not an abstract concept. It is a challenge, an obligation, and a necessity. Whether we are involved as technicians, scientists, or politicians, the public expects us to meet the challenge—and we should demand it of ourselves.

DISCUSSION

Comment: I presume that California, as most States, has some form of a non-degradation policy incorporated into the water quality standards. Could you describe that policy, and how or whether you are implementing it, and what kind of success you've had?

Mr. Towner: We do have such a policy, in Section 13000 of the California Water Code. I hesitate to get into the details of it. We've had it for some time, since 1949.

In California, the administration of water quality and the Federal Act responsibilities are with what we call the State Water Resources Control Board. This is a five-man board. Then we have nine regional boards. All have non-degradation policies. Your best bet for details is to contact the Water Resource Control Board in Sacramento.

Comment: From the perspective of the State government agency, do you feel that P.L. 92-500 has established a reasonable and workable balance between Federal, State, and local government sharing of responsibilities and funds for achieving or maintaining the integrity of water?

Mr. Towner: I think it is not perfect, but it is certainly a step in the right direction. It's not self-effectuating and the administration, I think, is as important as the law itself. I recognize that there are some critics in some areas, but overall it has worked in California.

On the construction aspect of it, as you know, the Federal government puts up 75 percent and the locals have to put up 25 percent. In California, the State is putting up 12½ percent, so a local agency only has to pay 12½ percent of the cost.

We've done this by two bond issues, one in 1970 and one in 1974, each of them for $250 million, so we've had $500 million to work with.

The point I'm trying to make is that you can't rely solely on the Federal Act itself. I think the States have to do something, both in spending some money on project development and on staffing.

Comment: In the 1974 Municipal Needs Survey conducted by the States for the purpose of identifying publicly owned wastewater collection and treatment facilities needed to implement water quality standards, as I recall the figures now, out of about $350 billion nationally, California has about $90 billion of that. I believe, far and away, the bulk of it was in a category of needs that has only recently been considered important, mainly control of urban stormwater runoff. Do you see $90 billion lying around anywhere to solve those problems?

Mr. Towner: No, I certainly don't. I know that California has more than its share of problems and of course in the big areas, the southern California area, you get what they call "flash floods." Millions of dollars have been spent there just on getting rid of the water when it falls because when it runs off, unless you have proper channelization, it can take a number of people and a great deal of property with it.

Comment: As a lawyer, what is your definition of integrity?

Mr. Towner: Well, to tell the truth, before I came, we had time to go to a couple of dictionaries and look for definitions. Integrity, I think, as we use it here, or at least as we were trying to use it in our paper—

Comment: I didn't ask for the interpretation; I'm not a lawyer, so I don't know. What would be a legal definition of integrity?

Mr. Towner, I don't know. I'd have to go to the law books and check that. We didn't do that.

Comment: What is your opinion?

Mr. Towner: Well, I think with respect to water, it means the highest and best use of the water.

Comment: Best use, then how would you interpret that in terms of the water quality? Would you say that this means that we have to maintain that best use everywhere?

Mr. Towner: The best we can.

Comment: That's a shade away from it.

Mr. Towner: As we mentioned in our paper, many of us would like to maintain some streams in the wild state. In other words, don't monkey with them in any way whatsoever. In many cases, however, this just isn't possible.

Comment: No argument. What about some of these fault problems in California?

Mr. Towner: We have to solve them. We are working towards it now.

Comment: I mean that you are going to tolerate that from the standpoint of integrity? You feel that doesn't affect the integrity or it does?

Mr. Towner: It does if you are using water so that ultimately you are going to irreparably damage the source—by ruining the ground water, for example.

Comment: There are a couple of more words coming in there. You've gone from clear water, rushing streams, and so forth, to damaging irreparably, and that is a big gap.

Mr. Towner: Let me tell you. In the San Joaquin Valley we are drawing down our groundwater table several feet each year. We've got to ultimately recharge that. That is just the groundwater problem. Also, there isn't an adequate master drain now, and the waste discharges, while not yet irreparably affecting the ground water, aren't doing it any good. Ultimately, they could damage it so it can't ever be reclaimed.

Comment: How do you justify?

Mr. Towner: You don't. Therefore, we're going to do something about it before it is too late. Our State Water Project has cost the State government $2 billion to date. An authorized unit is the master drain in the San Joaquin Valley; when this is built, it will get rid of that salt. It will take it out to the ocean.

The problem here is that this drain will cost maybe $200 million, and at the present time, the landowners in the San Joaquin Valley are unwilling to undertake full repayment. So it is stymied. Perhaps the statewide interest will be considered adequate in the future to build it without complete repayment.

Comment: We've had discussion on the previous day about your problem and the solution. We're wondering, what is integrity and what is the intent of the Act, where do we go from here—can we. That is what I am trying to bring out of you as an attorney.

Mr. Towner: I wish I could definitely answer your question. It is a challenge, that is all I can say for sure. But I appreciate the opportunity to wrestle with the problem.

A CONSERVATIONIST'S VIEW

RONALD OUTEN
Natural Resources Defense
Council, Inc.
Washington, D.C.

There is one point that is often overlooked in discussions about the "integrity objective" of the 1972 Amendments. That point is that the statute specifically calls for an assessment by EPA of the factors necessary to restore and maintain physical as well as chemical and biological integrity of the Nation's waters.

The point is overlooked, I think, because the discussions usually take place among water quality engineers whose primary attention is to the filtered water sample. My point is that the Act seeks ecosystem integrity and recognizes that all three components—chemical, biological and physical—must be addressed. Rather than belabor the point here, I would like to introduce into the proceedings at this point a letter to EPA on the subject written by my organization last year.

April 11, 1974

Mr. Kenneth M. Mackenthun
Director, Water Quality Criteria
Office of Water Planning and Standards
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Dear Mr. Mackenthun:

Pursuant to Section 304(a) of the Federal Water Pollution Control Act Amendments, EPA is to publish criteria for water quality which:

> accurately reflect the latest scientific knowledge (A) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, aesthetics, and recreation which may be expected from the presence of pollutants in any body of water . . . (and) (2) shall publish . . . information (A) on the factors necessary to restore and maintain the chemical, physical, and biological integrity of all navigable water, ground waters, waters in the contiguous zone, and the oceans; (and) (B) on the factors necessary for the protection and propagation of shellfish, fish, and wildlife for . . . receiving waters . . . , and (C) on the measurement and classification of water quality; - - -

To fulfill the above mandates, EPA published in October, 1973, two draft volumes entitled Proposed Criteria for Water Quality: Volume I and Proposed Water Quality Information: Volume II. NRDC will shortly be commenting on the adequacy of these two volumes with regard to the stipulations of Section 304(a). This letter deals preliminarily with the glaring omission of two categories of (1) "factors necessary to restore and maintain the chemical, physical and biological integrity of all navigable water;" and (2) "factors necessary for the protection of shellfish, fish, and wildlife," which these draft volumes totally neglected to address.

One category of "factors" is generally referred to as "physical modifications" of natural watercourses and associated wetlands that are integral to the aquatic life systems with which Congress is concerned in the Act. The proposed Criteria and Information documents completely ignore physical modification techniques—dams, impoundments, levees, channelization, fills—as threats to the physical, chemical and biological integrity of the Nation's waters and as destroyers of aquatic habitat, the very physical conditions that are essential to the protection and propagation of shellfish, fish and wildlife.

We believe that these two documents, particularly the Information document implementing Section 304(a) (2), must also fully discuss the role of swamps, marshes, flood plains, natural channels, and stream beds, stream vegetation, et cetera, as "factors" in preserving the natural integrity of surface and ground waters and in permitting the propagation of fish, shellfish, and wildlife. They also must discuss the threats to these resources and what can be done about these threats. EPA should face the fact that its proposed Water Quality Criteria could be fully satisfied with water traveling in a concrete trough, pollutant-free but hardly reflecting the natural integrity which Congress intends to have restored and maintained pursuant to this Act.

The goal of the Act is the restoration and maintenance of the "*natural* chemical, physical and biological integrity of the Nation's waters" by 1985 (Muskie). The House Report defines "that ecosystem whose structure and function is 'natural' (as) one whose systems are capable of preserving themselves at levels believed to have existed before irreversible perturbations caused by man's activities." (Leg. Hist. Vol. I, p. 764).

The word 'integrity' as used is intended to convey a concept that refers to a condition in which the natural structure and function of ecosystems is maintained.

As a concept, natural structure and function is relatively well understood by ecologists both in precise terms and as an abstract concept in those few cases where specific modification is not confidently attsinable.

Although man is a 'part of nature' and a product of evolution, 'natural' is generally defined as that condition in existence before the activities of man invoked perturbations which prevented the system from returning to its original state of equilibrium.

This definition is in no way intended to exclude man as a species from the natural order of things, but in this technological age, and in numerous cases that occurred before industrialization, man has exceeded nature's homeostatic

> ability to respond to change. Any change induced by man which overtaxes the ability of nature to restore conditions to 'natural' or 'original' is an unacceptable perturbation. (Leg. Hist. Vol. I, p. 763)
>
> The "1972 Water Quality Criteria" prepared by the National Academy of Sciences recognizes physical modifications as responsible for the degradation of those very life qualities which the Act intends to restore and maintain in the Nation's waters (Vol. I, p. 124). The destructiveness of these techniques on the very ecological values the Act intends to protect has been well documented. Further, recovery of natural systems destroyed by such techniques is frequently meager and typically slow. Such a process of degradation is not allowed under the Act.
>
> In sum, we feel that EPA is legally bound to include in the final version of its Section 304(a) documents a full discussion of the integrated physical character of the aquatic ecosystems and the effects upon this natural integrity of physical modification techniques. A discussion of these engineering techniques should address both their direct impacts and their indirect impacts on water quality through increased pollution loads, e.g., sediment, nutrients, pesticides, heat, et cetera.
>
> We feel that EPA cannot, from a legal standpoint, postpone the issues posed by physical modification since Section 304(a) calls for use of the "latest scientific knowledge." The "*latest* scientific knowledge" is replete with information on the effects on water quality, shellfish, fish and wildlife of physical modification techniques and EPA therefore has legal responsibility to include a discussion of these techniques, their consequences, and changes in the use of these techniques to bring their consequences in conformance with the overall objective of the Federal Water Pollution Control Act Amendments.
>
> We would like to see this issue resolved immediately, so that the more difficult task of implementing this requirement of Section 304(a) can begin quickly. A prompt response from you would be appreciated.
>
> Sincerely,
> Tom Barlow
> J. G. Speth

On Monday Mr. Jorling and Dr. Squires made a point that the 1972 Amendments marked a profound change in the philosophy and approaches to water pollution control in this country. The point bears reemphasis because even after 2½ years of living under the new law, a discouraging number of the people actually implementing haven't changed their thinking at all.

The fact is you cannot effectively implement the '72 law using 1965 assumptions. Consider the old law. It was premised on the anthropocentric idea, as Mr. Jorling pointed out, that aquatic ecosystems exist for the use of man.

This assumption leads one quickly to one perverse result after another. The first order of business becomes the designation of the "best use," basically a ratification of the status quo, a legitimization of the ecological abuse that had been previously visited upon the system. If a waterway is already an industrial sewer, it wouldn't make much sense to designate its best use as primary contact recreation.

Next comes the creation of water quality criteria. These are concentration levels for various pollutants, usually only a few easily measured ones, defining the limits which, if exceeded in the aquatic system, would impair its ability to serve man in the way assigned to it.

Underpinning this process is the ecologically questionable notion of assimilative capacity, the idea that extraneous materials placed in the water somehow go away. Not even simple carbohydrates are degraded without causing a response in the dissolved oxygen regime, probably the carbonate equilibrium, and certainly the types and relative abundances of organisms present.

Invoking the theory of assimilative capacity, and to avoid the obvious but unpleasant fact of finding dischargers in violation right at their pipe, one is led to the device of defining a mixing zone. A mixing zone is a sort of ecological free-fire zone where anything goes. The mixing zone moves the point of regulatory control far enough away from the discharge to make it very hard to assign blame for whatever violation might be found. It also leads to a curious circularity typified by a proposed procedural guideline I once saw; it said that finding water quality criteria consistently violated outside the mixing zone may indicate that the mixing zone as defined is too small.

Use of this sprawling regulatory scheme to actually abate a source required the execution of a load allocation, whereby the hapless erstwhile regulator had to allocate, based on assumptions about flow regimes, distribution of sources and waste stream constitutents, dispersion characteristics, and more, a portion of the total allowable load to each pipe.

Even if by great good fortune and Herculean toil this much were accomplished, the regulator found himself up against a whole series of enforcement delays, conferences, and admonitions that he not cause the unfortunate polluter an economic hardship.

Some States were able to make a little progress under these conditions, but where pollution was abated it usually was less the result of vigorous application of these procedures than the result of what one analyst has described as "gun twirling." Nationwide, it didn't work very well, and that's no surprise.

Note that all the steps in the process flowed logically from the first assumption, that the aquatic ecosystem exists for the use of human society. With the 1972 Amendments, on the other hand, we have for the first time in the Nation's history a water pollution control law that takes a holistic view of the aquatic ecosystem. For the first time, the objective is the restoration and maintenance of ecological integrity, not the perpetuation of somebody's notion of "best use." For the first time there is the recognition in law of the fact that man tampers with the fabric of the biosphere at his own peril, that the options of human society are best preserved by preserving the integrity of the biosphere on which all depends.

One may well charge: This is very grandiose, perhaps even profound. Did Congress know what it was saying with these words? To answer this we need only consult the legislative history and the Act itself.

From the report of the House Public Works Committee: "The word integrity is used to convey a concept that refers to a condition in which the natural structure and function of ecosystems is maintained." This bears remarkable similarity to the definition of ecological integrity put forth by Dr. Frey earlier.

From Section 502 of the Act: "The term pollution means the manmade or man-induced alteration of the physical, chemical, biological, and radiological integrity of water."

Senator Lloyd Bentsen, in floor debate on the Senate Bill: "We urgently need this declaration of National policy, at a time when environmental pollution desecrates the quality of our lives and even endangers human survival. It is an eventual goal which abandons any concept that water has an assimilative capacity with respect to pollution, and it is, therefore, a decisive redirection in National policy."

Senator Cooper, also in the Senate debate: "I believe the Bill and its purpose go even further than asserting that a public right resides in clean water. In a way, it recognizes an even more fundamental condition. It asserts the primacy of the natural order on which all, including man, depends. It declares an intention to restore the natural integrity of the Nation's waters."

Senator Muskie, in the Senate debate on the conference report: "These policies simply mean that streams and rivers are no longer to be considered part of the waste treatment process."

And elsewhere: "This legislation would clearly establish that no one has the right to pollute, that pollution continues because of technological limits, not because of any inherent right to use the Nation's waterways for the purpose of disposing of wastes."

I don't think there is any doubt that Congress knew what it was about when these words were enacted. Having stated this far-reaching objective, Congress went on to say that to reach it we must first obtain a goal of no discharge of pollutants by 1985, and even before that an interim goal, wherever attainable, of water quality capable of supporting fish and wildlife propagation and recreation in and on the water by mid-1983.

To back up these rather dramatic goals, several no-nonsense regulatory programs intended to cover point source discharges, toxic pollutants, and industrial discharges to municipal systems were established. Even nonpoint source pollution got some long overdue attention. There is a requirement that regulatory programs be established in all parts of each State to implement plans designed to reduce nonpoint source pollution. These programs are to contain land use requirements wherever needed to do the job.

Congress also inserted a number of economic safety valves, variances, in these regulatory requirements. The Water Act is not going to shut down American industry.

All this leads me to several observations and conclusions about the way we ought to be viewing the integrity objective and what EPA could and should do to get us moving faster in the direction of achieving it.

A corollary of the integrity concept and the definition of pollution which tracks it is that there is no such thing as "natural pollution." A ramification of it is that assimilative capacity becomes obsolete as a justification for polluting the water. In fact, the words, "assimilative capacity" and "mixing zone" do not appear in the Act.

The question, "How much cleanup is necessary?" becomes a meaningless question in terms of the ultimate objective, though not in terms of the interim water quality goal.

It is not possible at this time to define the integrity objective by any index or system of water quality parameters. There is too great a diversity of natural conditions, conditions we can only infer. Integrity is thus not a regulatory tool in and of itself. It does not require us to reforest the eastern seaboard, dismantle our cities, and board the Mayflower for Europe. It is more a statement of philosophy, a statement of National direction. It is not a meritorious criticism of the current law to say that its ultimate objective is difficult to define quantitatively. We have some good interim goals, which can be translated into effluent restrictions, to achieve first. We should get about the business of doing that.

EPA could get this country moving along the course that has been set by screwing its bureaucratic courage to the sticking place and starting to implement the law with a modicum of vigor. NRDC has felt compelled to bring eight lawsuits already in attempting to get the Agency to abide by the bare letter of the law, and most of the regulations and guidelines that are central to the Act's operation have come out under court order.

On the other side, industry has brought about 150 lawsuits to overturn the effluent regulations set for them. It is a real brawl, and the program is sputtering along.

This conference is itself an example of the Agency's approach, where the Act requires the Administrator to develop and publish information on the factors necessary to restore and maintain physical, chemical, and biological integrity. The Agency will, I am told, publish these proceedings and call that compliance with the law. Where the Administration is required to consult with outside groups, then explicate the objective of the Act, EPA will publish the consultation itself and thus avoid giving Agency approval to the "controversial" ecological principles that Congress accepted without too much trouble.

Further, we will not see real progress until we get ourselves detached from the "chlorinate and dump" mentality. This means EPA must start to fulfill its statutory obligation to encourage innovative municipal treatment technologies, especially land recycling.

More broadly, and here I will compound the heresy, we will not get there until we break the death grip that the sanitary engineering and economics professions have on all decisions regarding the way that essential materials circulate through society. The sanitary engineer must make room for the systems ecologist, the soil scientist, the agronomist, the hydrologist, the forester, the microbiologist. We need a team approach, not a pure engineering approach, to solve a problem that is affirmatively not an engineering problem.

We must recognize that the field of economics is unequipped to deal with the broad questions of ecosystem structure and function and therefore the quality of life we want a century, two centuries, from now. How do you compute the price of an element in the food chain that is not destroyed? What is the cost or benefit of a unit shift in the Shannon-Weiner Index?

Rather than responding to individual treatment crises on an ad hoc basis, rather than taking the action and then measuring its effect, we must elucidate fundamental ecological principles, then guide all human behavior by those principles.

DISCUSSION

Comment: I'd like to ask, what is your interpretation of the quality of water necessary for people to recreate in the river. In other words, what standards of perfect health would you require of river water before you swim in it?

Mr. Outen: I certainly don't have the concentration levels for each relevant parameter in my head, but I think the best cut we have of that at the moment is the water quality criteria document which has been proposed by EPA, but not yet finalized. The document flowed from, in some sense, the work of the National Academy of Sciences, which was a much larger effort and spanned several years.

I would say one other thing about that. Not only do we need to get that water quality criteria book out, (it was supposed to be done in October, 1973, was proposed then and hasn't been finalized yet), we must make sure that the water quality standards that now exist are upgraded, and upgraded in time to influence and condition the setting of permanent levels for 1983, in the second round of permit issuance. Those standards must include numerical criteria for all pollutants for which a numerical criterion is appropriate. Those criteria that are duly adopted by the States must be at least as stringent as those in the 304(a) document or present a very strong reason why this isn't the right thing to do. I can't think of any at the moment, but I'll leave myself that out. There is the further requirement that water quality standards throughout the country be upgraded to a level consistent with the 1983 goal in time to condition 1983 limits in permits.

Comment: If you return the rivers to their natural condition, do you think they wouldn't be polluted with all of the millions of buffalo and animals that were supposedly running around this country 100 years ago?

Mr. Outen: It would n[illegible] be polluted under the definition of pollution in the Act, nor under the concept of integrity espoused by Congress. It is a corollary, as I said, that there is no such thing as natural pollution.

The fact that the Yellowstone Hot Springs were hot is no justification for making cold waterways hot. The fact that coliform bacteria existed before the white man, at least, and disrupted the system so badly, is no justification for coliform levels of the sort we are now creating.

Comment: I can't resist trying to clarify one point on your comments on capacity. You said that introducing carbohydrates would make a change in the system and because of that there was no such thing, at least that is the way I interpreted it.

That would mean a leaf falling into the stream would change it. I think the important point is the deleterious changes induced or caused by the introduction of these materials. Equally important, I think we will agree for many compounds, there is a possibility of introducing waste materials without causing any identifiable or demonstrable deleterious effects, not just changes or responses, but measurable deleterious effects.

I don't expect you to agree with this, but if that were the case, then it would be the assimilative capacity.

Mr. Outen: There are two points that spring to mind. The first point is: deleterious to whom or what? The second point is that I'm personally not very reassured by the statement of some that we can put things in the water that we are then unable to measure. The first example that springs to mind, it might not be the best, is that rising levels of exotic chemicals in the water may disrupt the spawning system of fish who are confused by the noise introduced into their chemical communication system. We may not be able to measure them, we may not know what they are, we certainly will not know that they are going to disrupt chemical communication systems, but it might happen.

The prudent thing to do would be to make all due haste in the direction of not creating that sort of potential problem anymore.

Comment: Mr. Outen, you mentioned that a key step toward achieving water quality in this country was to break the death grip of the sanitary engineering profession on our sewage treatment practices.

I want to make a statement that closes with a question about "turnkey" contracts. Sanitary engineers are almost alone among engineers in this country in never guaranteeing the performance and the capital costs, let alone the first year operating and maintenance costs, of the plants they design.

These sewage treatment plants are sold to local governments and to EPA on the basis of certain removal rates that will allegedly be met. Almost invariably during the course of a year, or a quarter, or a month, or even a week, these rates are not met in actual practice, but the sanitary engineers who designed the plants get off scot free because designers and builders do not share any legal responsibility for successful operations. We do not have a requirement for "turnkey" contracts that would impose cost and performance guarantees. While EPA now accepts this turnkey process, it has not mandated it.

In conversations with the people who designed the Muskegon County (Michigan) Land Treatment System, I have learned that they would be willing to live up to cost and performance guarantees for their sewage recycling designs in the future.

In conversations with more traditional sanitary engineers, however, I learned that they would not meet such guarantees because their stream disposal can't handle diurnal flow oscillations, dry weather-wet weather flow oscillations, and so forth. My question is, would you support the idea of mandating turnkey contracts with cost and performance guarantees for the sanitary engineering profession in this country?

Mr. Outen: I think yours is a very sound analysis and I think that would be a very small and easy step to take. It would have enormous importance. Yes, I would support that.

Chairman Sager: I have to take exception to the last remark about sanitary engineers and I have to say that I have the highest regard for agronomists, ecologists, foresters, all of the basic scientific disciplinarians who have added to the field of environmental knowledge through their various disparate disciplines over the many years. I would like to point out, however, that sanitary engineering is, in a sense, a comprehensive science because the sanitary engineers of my acquaintance are also biochemists, organic chemists, microbiologists, as well as structural engineers, people who understand thermodynamics, who understand the physics of hydraulics, and so on.

I would hate to see what would be the case in the District of Columbia at the present time if 280 million gallons of raw feces and urine flowed down the street without the expertise of the sanitary engineers.

I also have to take exception to the remark that was made that industry has gone to court to try to avoid or evade the limitations which have been put out for them by the Environmental Protection Agency. Although there are court cases, I personally believe that the idea is not for industry to evade discharge limitations. In the first place, the Act has a pro forma clause built into it which says that anyone who wants to sue for any reason at any time should file suit within 30 days.

Most people who read the small print at the bottom of the page go ahead and have their attorneys file a suit against the Agency so that they may then review what has happened. In many instances, and I think even the people in the Environmental Protection Agency who have worked on these limitations will not deny, the constraints put on the contractors because of the time frame allow little opportunity for data collection and particularly data generation for those industries who did not have to have it, of collecting data.

Therefore, many of the limitations, industrial limitations, that came out under Section 304 and 306, were incorrect. There is no way to put a pointing finger at anyone who is culpable. No one person is a part of the total operation of meeting technological and scientific deadlines under a time constraint and I, personally, believe, and I believe I can justify my statements here, that those which are incorrect are incorrect for the reasons which I gave and the industries have gone to court to protest the incorrectness of them. The Agency will work to revise and has already started to revise them.

I'm very pleased with the idea and the interpretation of the Natural Resources Defense Council about maintaining and trying to return natural ecosystemic balance.

I think everyone in the room has heard today, and probably yesterday from Ruth Patrick and the other ecologists who have spoken, that we all depend on a natural ecosystem. I personally can stop my car when I see children running across grass and breaking off trees and so on, and try to point out to them that we are dependent on the green plant also.

Comment: I didn't mean to criticize the sanitary engineering profession for its 19th century accomplishment of getting viruses, bacteria and other pathogens off our streets and into our rivers. That was a necessary stage of development, but it is no longer acceptable.

What I am proposing, basically, is the accomplishment of tertiary sewage treatment on the land. Most sanitary engineering firms do not have soil, crop marketing, and agronomic specialists on their staffs, nor have they worked with these specialists under contract.

This biases them in favor of the river or lake disposal approach, and they end up throwing perfectly good nitrogen fertilizer into the water. They're going to continue doing this right here in Washington at the Blue Plains tertiary plant because the methanol cost of denitrification has skyrocketed out of sight.

When we throw away sewage nitrogen, it forces us to produce nitrogen fertilizer which consumes large amounts of natural gas and electricity and also eventually degrades the soil because it lacks organic matter.

It is the sanitary engineer's failure to take this holistic view of things that Mr. Outen was trying to get at. I think he was justified in his criticism of the sanitary engineering profession.

Chairman Sager: I, myself, am an ardent supporter of land-based treatment systems as my many students can attest to. However, I personally don't believe there's one solution to any one of these problems. I don't believe there's one solution for all the Nation's waterways. I believe we have different solutions depending on the situation within the waterways.

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Socrates once said that if any man intended to argue with him, that man should first define his terms. "The integrity of water" is certainly a term needing definition. This entire session, in fact, has been devoted to the discussion of possible interpretations of this seemingly simple phrase. Socrates would have appreciated our attempt to define terms.

The dictionary defines integrity as the soundness, the state of being, the honesty, or wholeness. We have been trying thus far to decide just what meaning Congress did intend. I would like to approach this question from the other side. I would like to consider just what Congress probably did *not* intend.

First of all, then, it might be well to point out that "integrity" does not necessarily mean "virginity." These two words may have the same meaning in a specific instance, but they are *not* synonymous. I feel certain that Congress had no thought of considering them to be so when it included them in Law 92-500.

In the second place, King Canute demonstrated a great many years ago that inanimate objects such as large bodies of water do not readily respond to public decree.

One method of classifying all things in this world is to divide them under the three headings of solids, gases and liquids, but this is a classification of the inanimate. I believe that it is meaningless to talk of "maintaining the integrity of water"—the integrity of an inanimate thing? Rather we should be stating it as "integrity in the use of water."

In the third place, it seems highly improbable that the intent of Congress was to create a favored part at the expense of a remaining and less-favored whole. One does not put a smooth top on a table by first creating an optically flat surface of one square inch in area and then moving on to another square inch. You start by sandpapering the entire surface and then going to finer paper, then to pumice, then to rottenstone, and finally to optical polishing. Your goal—which you must never lose sight of—is to arrive at a smooth tabletop; and a square inch of mirror surface is not that goal, particularly if in accomplishing it, you seriously roughen or gouge an adjacent area. Just so must we, in our sincere, justifiable and laudable concern about the environment of our space ship, Earth, be careful to avoid what I call "The Optical Flat" syndrome.

There are encouraging signs that the danger of this syndrome is being recognized. There was a period in the early seventies when the reverberations arising from the beating of breasts, and the alternate thumping of chests threatened to drown out the quiet voice of reason. It never happened, fortunately, and that voice can still be heard quite clearly—if one will just stop and listen. But we must listen carefully and to all that it has to say, for this is a complex world. In fact, the complexity has become like the mythological giant Antaeus, who could be knocked off his feet but would arise again, 10 times stronger than before. In the same fashion, each problem solved today seems to cause 10 new ones to arise. Accordingly, we become confused at times and unsure of which way to turn. We are well aware that we cannot exist indefinitely on earth if we continue to act in the future as we have acted in the past. But what should we be doing? We know how to distinguish between the experts and the pseudoexperts but the experts themselves are disagreeing. We are grateful, therefore, for that quiet voice of reason and the advice that it gives us.

In the first place, reason says quite simply that no cataclysm is imminent, but that there are some on the way if we don't take the appropriate action to prevent them. A bomb squad confronted with the problem of defusing a series of time bombs always starts with the one suspected of being set to go off first. We must proceed in the same manner. Is our bomb a discharge of raw domestic sewage that could start an epidemic next summer, or is it a particulate problem in the upper atmosphere which, by reducing the solar energy reaching the earth's surface, could bring on an ice age in a few thousand years?

Secondly, reason continues, we cannot wait to start corrections until we can have 100 percent assurance of success. Someone has to be first. There is no such thing as certainty. Nothing is ever done without risk in this world. However, reason's risk does not mean playing Russian roulette or betting all that you have on the "come card" in life's poker game.

Thirdly, reason is the power of comprehending facts in an orderly or rational way. We must be certain, therefore, that all known pertinent facts are considered. What is more, new facts are being added continuously and, as new facts are introduced, reason's conclusions will change. In this third point lies one of our biggest problems. How do we know that the conclusion which we may have reached would not have been different had we but had more facts, more truth, a broader perspective? If reason is to stand up, it must be based on all the essential facts. Reason is, therefore, concerned with the whole.

Maintain the integrity in the use of water? What about integrity in the use of air or land or people? What about integrity in the use of that basic essential of all living things, namely, energy? Mankind must be concerned with the integrity of the whole since mankind is the only form of animation on the face of the earth which is capable of so doing.

The whole! Trying to grasp the concept of the whole boggles the mind. Yet, immense as the problem is, it must be dealt with. For this presentation, I have chosen to separate the whole into two parts: the animate and the inanimate, and have specified our concern as being with the animate.

All animation starts at the same place—viz, with energy. (Perhaps the old sun worshippers weren't too far off after all.) But while all animation may start with energy, it ends with people. At least it does today. It didn't millions of years ago back in the age of reptiles, and maybe it won't millions of years from now, but it does as far as we are concerned, and the integrity of the whole can then only be judged as it relates to people.

People! Old people, young people, professional people, people in public office, people in industry, people privately employed, people, people, people. After all, doctors or engineers, white collar or blue collar workers, legislators or educators—all have a common denominator. They are all people. And all require two basic things if they are to exist—energy and economic adequacy. Sometimes we may lose sight of this latter fact, but usually not for long because someone will bring us to an "about face" (and it is usually a somewhat "shamed face"). Professor Henry Luce, writing recently in the Wall Street Journal, gives one of the best examples of how goals may be lost sight of. He said: "Sometimes it would appear that the goal was not to protect Americans from dirty air, but to protect clean air from Americans."

Another way of describing the integrity of the whole is by simply referring to it as "balance." In industry, just as outside industry, balance refers to the portions of energy and economic adequacy allotted to different people—to raw material suppliers, to transporters, to manufacturers, to equipment suppliers, to distributors, to consumers, so that they can all be fed and clothed and housed and obtain satisfaction from life.

I would like to comment at this point on those two phrases frequently heard; namely, "the balance of nature" and "keeping nature in balance." I would point out that nature *is* balance. She takes what she has available and brings it into balance by means of her natural laws. To talk about the "balance of nature" is like talking about the "wetness of water."

Man and his ingenuity are a part of nature or of balance. If it were left to nature without man, it would become a question of the survival of the fittest, like the caribou herds who are kept free of the diseased and the weak by the wolf packs. We would then become a civilization of weight lifters and linebackers and prize fighters—no Mozarts or Edgar Allen Poes. No Byrons or Robert Louis Stevensons. After all, nature's ingenuity results only from her variety. Man's variety results from his ingenuity.

I suppose that there are few thoughtful people who would dispute the point that successful life is a matter of balance. The difficulty arises from the fact that everyone thinks that he or she is standing on the fulcrum.

Also, I would point out that in no way do I apologize for the profit motive—in no way! I can say this as an individual as well as a representative of industry. Everyone has the profit motive! The average filling station employee doesn't pump gas so that more people can see the beauties of America; or the average plumber clean out a septic tank so that less strain will occur to our biological environment; nor does the average doctor or nurse or lawyer or taxi cab driver or farmer have as his prime motive the making of this world a better place to live. In many cases, thank heaven, it is a motive, but it is usually a secondary one. I have known certain doctors and ministers, a number of social workers and a nurse or two, whose primary aim was to make people happy. I wish there were more like that. I also have known certain industrialists whose primary goal was to make their communities better places to live in. I wish there were more like that, also. But let's face it, the great majority of us are motivated by more than the goal of having enough food to eat and clothes to wear and a roof over our heads. We want to improve our standard of living. This means that we want things that we don't absolutely need. If there are those in the audience to which this statement does not apply, I salute you. But you are not in the majority. In fact, you are not even a very large minority and, if you will honestly review in your minds the many people that you know, you will agree with me.

And I do not believe that this is a criticism of the rest of the world because they happen to feel this way! I believe that the definition of "profit" should be changed from the dictionary definition which calls it: "The excess of returns over expenditures," to the more realistic one that would define profit as: "The attainment of a better life."

Just as Socrates was annoyed by a lack of definitions of terms, so also am I irritated by a misuse of terms. I refer specifically to a name used so indiscriminately by our friends in the media that the term is threatened with complete perversion. The word is "environmentalist," when the phrase "environment-minded" should be used.

We all continually see headlines that cite some conflict between the "Environmentalist" and Industry or Commerce or Educators. This is just not reporting the situation correctly. There are environmentalists on both sides of most cases—people who are studying the integrity of the whole. Usually, however, the individuals dubbed "environmentalists" are not qualified for such a designation, having read only the first chapter of the book.

As a member of the paper industry, of course, I would be very hesitant about criticizing the media—especially the press. I hasten to suggest, therefore, that perhaps a change in the definition of the word "environmentalist" would be the best way to compromise on the matter. A definition such as the following would probably satisfy all but the true environmentalists who, alas, do not constitute a strong voting block. "An environmentalist is a man (or Ms.) who is sincerely dedicated to the task of improving the environment—and is so certain that he knows how it should be done that he is willing to bet all your money to prove or disprove his theory."

These individuals may be sincerely dedicated to preserving the world in optimum condition for future generations, but an individual is no more qualified to be termed an environmentalist just because he is environment-minded than he is to be termed an economist just because he is economy-minded. And yet this misuse goes on and on.

But back to the subject of maintaining the integrity of the whole, the thesis of my talk today: How can we avoid the "optical flat" syndrome?

First of all, we must learn to get far enough away from the immediate problem to be able to view it in perspective. We all are amused by the story of the blind men and the elephant, for we all appreciate that if you would accurately describe an elephant, you should stand well back—particularly if it is a wild elephant. Yet, how many of us see only the desirability of solving the problem at hand and not the future consequences of that solution.

The concept of the environmental impact statement has opened the window to a broader perspective. Many of these statements, however, have been off to false starts and some are falling by their own weight. Here again, the fact is sometimes being lost sight of that they are not goals in themselves, but only means to an end and can easily become optical flats. They are, however, headed in the right direction toward an "integrity of the whole" and, in the process, are making more and more individuals consider more and more factors. The big research agencies of the Nation are going deeper in their studies and looking into side effects more than has ever been the case in the past. There is an encouraging glow on the horizon.

But blind men still cling to elephants' trunks and in so doing impede progress. Means are still being confused with ends. In the latter connection, I grow very weary of hearing the argument given for some particular scheme that it is technically feasible. Usually this point is delivered thunderously and draws thunderous applause from some active contingent in the audience. In rebuttal, I usually point out that it is technically feasible to build an 18-lane highway from Washington to New York City.

"Why don't we do it then," I ask. "With nine lanes of traffic going each way, with the speed of each lane carefully regulated, it would certainly be safer. Perhaps someone in this very room today may be killed in an accident on the present highway to New York, an accident that would not have taken place if there had been an 18-lane highway. Isn't a human being's life worthy of consideration?"

I never press the audience to really answer the question—I just want them to think about it a little.

Absurd as this example may sound, it has its counterpart in everyday life. Far too many regulations are being proposed today on the basis of data demonstrating them to be attainable rather than with data demonstrating them to be needed.

Another example of the optical flat syndrome is the attempt to go too far too fast in correcting some existing problem with no consideration given to the side effects that may develop. Pressure for rapid increases in the percent of recycling is one example. These pressures sometimes take the form of new specifications for materials to be purchased by government bodies, or of boycotts of certain products by organizations on the basis of some arbitrarily required content of reused material. Such pressures, created in the worthy cause of extending our natural resources, may result in an effect which is exactly the opposite, simply because the whole problem has not been thought through.

In the paper industry, newsprint is an excellent illustration. Most of the newsprint is manufactured in northern Canada and the southern United States, but by far the greater part of it is used in the large cities. Newsprint is one of the cheapest paper products and you cannot make a silk purse out of a sow's ear in the paper industry any more than you can anywhere else.

The use of old newspapers is, therefore, pretty much limited to boxboard grades or the manufacture of more newsprint. The logistics problem, however, that would result from the yearly shipping of thousands of tons of waste newspaper over the thousands of miles of track to return it to its place of manufacture would create an added drain on our energy supplies. Also, one must remember that a single freight car will hold over half again the weight of newsprint rolls than it will of waste paper bundles, so more freight cars would be needed. True, the added use of energy would be partially offset by the reduced use of trees in the manufacture of newsprint, but the growth of trees draws no energy from our limited resources beneath the earth's surface. Rather, the source of energy for trees, like the source of energy for all living things, is the limitless source, the sun.

Quantities of old newspapers *are* recycled into other grades, as mentioned previously, but the amounts are based on the problem of the whole and recycling in other industries has similar limitations brought on by the overall picture.

Actually, recycling is nothing new. We have been recycling materials for generations and the amount recycled has sought its own level in each. We know that we will continue to recycle for generations and at an ever increasing rate. To attempt, however, to force an immediate change in this single area without regard for related areas is to attempt to create an optical flat—and a very small one.

Still another example is the insistence that action must be taken immediately even though the adequacy and the economic impact of the available technology may still be in doubt. Reason has stated that 100 percent assurance of the success of any project is a luxury we cannot expect, but in the same breath reason warns against Russian roulette. To embark on a venture, the failure of which would spell disaster for your company, is to play Russian roulette with both your investors and your employees.

A power company, for example, could hardly be blamed for resisting the installation of the lime scrubbing method for the removal of sulfur dioxide from the stacks when the solving of the air pollution problem by this method can be accomplished only by creating an equal or more serious problem in sludge disposal, a problem which the company would have to reckon with for all the foreseeable future. Some companies have allowed themselves to be pushed into going ahead with this method, but now a new citrate process is being proposed which, it is theorized, will minimize the solid waste aspects of sulfur dioxide disposal while accomplishing the necessary removal. What of the company that has shouldered not only the expense of installing the lime scrubbing process but has saddled itself with a horrendous sludge disposal problem, while the rest of the world has waited for the technology to develop and then gone down the new road?

Or again: We have had an excellent illustration in one of our Kimberly-Clark mills of the necessity of standing back to obtain an overall picture. As you may recall, it was only about 4 years ago that joint treatment of municipal and industrial wastes was being touted as the panacea for all pollution abatement problems. Authorities have backed off since then, but in 1970 and 1971 it was considered the "in thing."

The mill that I refer to is in a small town which was then (as now) under order to construct new and improved sewage treatment facilities. It was generally assumed that this was an ideal case, if there ever was one, for joint treatment. Half of the waste load would come from industry and half from the municipality. It would thus have all the well known advantages of joint treatment such as the economies of size, the superior supervision possible in one large plant, the elimination of proliferations of small plants, and a system which contained wastes that would neutralize each other. What is more, the Federal government would shoulder a major portion of the cost which, of course, in the minds of some, meant that that part would be for free. Consideration of the actual facts of the matter, however, revealed some additional pertinent points.

In the first place, the manufacture of sanitary tissue produces no pathogens or disease germs such as are present in all municipal treatment facilities. For this reason, it is not necessary to disinfect the 2½ million gallons of used water being discharged daily to the river from the tissue mill. Once mixed with the 2 million gallons of sanitary sewage, however, as would be the case in any joint treatment facility, the entire 4½ million gallons of effluent would have to be disinfected. This would mean using over twice as much chlorine as would have been necessary to chlorinate that portion needing disinfection.

This latter point was a telling one with the environmental-minded. The doubling of the cost of the process carried little or no weight, but the needless expenditure of energy in the production of the chlorine that would be completely wasted caused some of them to stir uneasily.

A second factor: Sludges from municipal plants of this size usually depend upon anaerobic digestion to render them innocuous. After anaerobic digestion they are dried and hauled away to be used in a landfill site where they eventually act as a much needed soil supplement. Contrasted with this, broken cellulose fibers, the sludge from a tissue mill, will not readily digest anaerobically and hence cannot be treated by this method. Since tissue sludge is innocuous as it leaves the mill, it can be hauled directly to landfill, soil amendment, or some similar disposal method. If it were to be mixed with municipal sludge during treatment, however, incomplete digestion of that municipal sludge would take place and State regulation forbade the disposal of undigested or raw sanitary sewage in landfill sites. Accordingly, if joint treatment were contemplated, some method other than anaerobic digestion would have to be utilized for disposal of the sludge.

Studies made by Kimberly-Clark showed that burning or liquid oxidation would more than double the cost of municipal sludge disposal over that of landfill disposal. However, the cost to the corporation would be considerably more than doubled, since Kimberly-Clark would certainly be expected to pay for the added cost of disposing of the municipal portion of the sludge as well as that originating from the tissue mill. After all, the city would be forced to go to this new method of disposal only because of the presence of industrial sludge. If this method cost the individual citizen more, it was maintained, industry should bear this added cost. You will admit they had a point.

From the energy standpoint, sludge disposal by incineration is never self-sustaining at all times. Supplementary oil or gas is always necessary. Again, this added energy requirement would be used to accomplish something that could be realized in another manner—landfill—a method requiring far less use of energy.

But, there was still another major factor that went into the final decision. Incineration would mean air pollution unless adequate steps were taken to prevent it. These adequate steps would not have been necessary if there had been no incineration. Incineration would not have been necessary if sludge could have been digested anaerobically. Sludge could have been digested anaerobically if there had been only a small percentage of cellulosic material present. There would have been only a small percentage of cellulosic material present if Kimberly-Clark hadn't agreed to participate in a joint treatment project.

Ergo—the cost of all air pollution abatement facilities and the energy required to operate them should rightfully be a Kimberly-Clark problem.

And so the final decision was for our corporation to build its own plant for treating our own wastes—a treatment designed for our own specific needs. This plant has been in operation for over 2 years and has been doing a very laudable job.

Any learned presentation dealing with some critical problem facing the Nation today always ends with a recommendation for immediate action by everyone. Action—usually drastic action—which the speaker is certain will completely solve the problem. In this discussion of the integrity of the whole, therefore, I too, would like to make a recommendation. It will not completely solve the problem, but it will certainly help and it is something everyone can do. Here it is.

In heaven's name, let's take a positive attitude! Let's stop beating ourselves over the head as though integrity were a thing of the past! Let's proclaim to each other and to the world that the last decade has seen a complete turnabout on the environmental front in this Nation. Let's give and take credit for the gains made.

A little over 3 years ago, I had the opportunity of discussing the environmental situation with Hugh Downs of Today Show fame. In the course of our conversation, I pointed out that in spite of the closing of some shellfish beds due to the buildup of bacterial contamination, and some instances of greater algal bloom laid to the increasing use of phosphates, things generally were starting to improve.

"Of course they are," Downs said. "Everyone knows that the smog in London in Charles Dickens' day was far worse than it is today. Fish are being caught in the Thames where no fish have been found for 100 years. In this country, reports come through almost weekly of some stream or river that has turned the corner and is now on the road to recovery."

"Why, then, won't anyone admit it?" I asked.

I thought his answer was a thought-provoking one.

"Perhaps it's because of the nature of the society we live in. It's a crisis society. Things have to reach crisis proportions before we will take action on them, and then we do and it's often violent action. I think that environmentalists are afraid that if it is ever admitted that things are getting better, the public will heave a sigh of relief and say, 'Well, that is taken care of. Now what do we worry about tomorrow?'"

I think that he was right. But, while he may have been correct 3 years ago, I would hope that, environmentally speaking at least, we are becoming big boys now. We had better be because it takes big boys to handle the whole problem.

In closing, I would like to read you a short poem written as I believe James Whitcomb Riley might have written it had he turned his Hoosier attention to environmental problems. I suppose that it might be considered a fairly long jump from Socrates to James Whitcomb Riley, but it is probably not out of place at this session. I have observed some of my environment-minded friends jumping further. At any rate, here are the immortal lines:

Environmental Protection's come to
our house to stay
To clean the lakes and rivers up
An' brush the smog away.
An' shoo the flies off of the dumps
An' bury pipelines deep.
An' monitor and prosecute
An' earn its board and keep.
An' all us other children
When we're feeling most perplexed
We get the Fed'ral Reg'ster out
To see what's commin' next.
For you'd better read the witch tales
That paper tells about
Cuzz the EPA will get you
If you don't watch out.

R. M. Billings

THE PUBLIC'S VIEW

GLADWIN HILL
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In the days of vaudeville, the star act always had a special position on the program. It was customarily made the next to the last item, on the theory it was a climax to everything that went before, but shouldn't be placed last because that was the time when people started leaving.

Therefore, I'm honored to be in the next-to-closing spot today. All personal considerations aside, I hope that the thought in putting the public's outlook near the end was not because that topic was an afterthought, but because it was considered especially important.

My main point this afternoon will be that the public outlook is not only important but is the most important aspect of all your undertakings.

You've all heard the old philosophical concept that a tree falling in the forest doesn't make any noise if there isn't someone there to hear it.

The same concept is true, in a very real way, of all endeavors that involve the public in general—and few things, of course, involve the public to a greater extent than water.

Whether your efforts on behalf of water quality are in government, science, private industry or conservation, those efforts are critically dependent on money. The ultimate source of all money is the public. And the public won't, in the long run, supply financing for a program or a project, no matter how worthy, unless the public is convinced that it is worthwhile.

We've all seen programs, even programs with merit, go down the drain because public support for them, for one reason or another, had evaporated.

The most frequent reason that public support evaporates is that the virtues of a program are not adequately communicated to the public. That is what I want to talk about briefly. Communications. I have no credentials in water technology or in water science, but I do have some 30 years experience in various fields of communications.

I think the two most important facts for people dealing professionally with water to realize are first, that the cornerstone of their work is public understanding; and second, that professionals, in the main, aren't communicating as effectively as they might because they don't talk and think about water in the same language as their constituents. I'll try to give you an example from another field.

About 1½ years ago the atomic power industry, worried about the rising resistance to nuclear power plants, sponsored a scientific opinion survey to find out how the public felt about nuclear power. The industry was very pleased with the results, which suggested that 80 percent of the public was favorable toward atomic power. I happened to be one of the speakers at a conference where these results were reported, and I'm afraid I was the skunk at the picnic, because I said that it seemed quite plausible that people, if asked whether they were for or against atomic power, would say they were for it.

But I suggested that this popularity was resting on sand if people had no real understanding of the pros and cons of atomic power. I asked the atomic power people, in the connection with real understanding, how many doorbells they thought they would have to ring before they found somebody who could give them even an intelligent definition of something as elementary as background radiation. It would certainly be a small minority.

Lack of understanding is why opponents of atomic power like Ralph Nader are having such an easy time knocking that 80 percent favorability into a cocked hat. I'm not saying Nader's right or wrong, but I'm saying that when the debate gets going and one side or the other doesn't have the ammunition, it gets knocked out of the box.

I think something of the same sort applies in the field of water. Everybody uses water; everybody depends on it; for hour-to-hour survival. So I think there is a subconscious assumption by many professionals that the public is as familiar with the nuts and bolts and pros and cons of water management as professionals are.

But, look at it this way: How many doorbells do you think you would have to ring, before you could get an intelligent definition of something as elementary in the water picture as BOD, or coliform, or deep well injection? How many laymen could tell you that salmonella isn't some kind of fish or a new dance?

Ten years of writing about water quality in its various forms have shown me that public knowledge on the subject is very limited. People think water is clean if it looks clean. Conversely, they panic if it has the least bit of color, odor, or turbidity. Most people don't even know where their particular water supply originates, let alone what it costs them. They have no idea of the processes that it goes through for purification. They don't know that a half dozen chemicals may be used.

You can see this when community disputes erupt about fluoridating water. People react as if putting any chemical in water—regardless of its medical merits or demerits and regardless of any civil liberties ramifications—as if fluoridation was, per se, evil because it amounts to tampering with water's pristine natural virginity.

The public is angry about water pollution, mainly because the result is aesthetically distasteful. And they are willing to put out quite a bit of tax money for water quality as long as the levy is rather invisible.

It is easier to raise a million dollars through Federal taxes for water pollution abatement than to raise $100,000 to improve the local community systems.

Finally, the public is impatient with the pace of water quality improvement. The average citizen builds a garage in a couple of months. He can't see why a sewage plant can't be put up in the same time.

Now, how does this limited public knowledge affect professionals in water quality? Well, as I've said, if people don't understand your programs thoroughly, you have a shaky foundation of support when the inevitable crunches come and some politician wants to divert funds from water quality to financing some outlandish project like the SST.

Secondly, in the meantime your program may get only anemic support. One of the great scandals of this country, I think, is the minuscule amounts States and localities and, indeed, the Federal Government, spend on assuring pure drinking water.

Jim McDermott and his colleagues labored over a decade to get passage of a drinking water bill whose need is as elementary as traffic signals. Citizens would be horrified if they knew that only a few cents per capita per year were being spent on surveillance and research to avert their being poisoned by bacteria and viruses.

I'll give you a specific example of how this public ignorance can affect your work. One of the big salients in water supply, as we all know, has been the procedure of purifying and recycling wastewater. That effort has proceeded slowly down the years, and one reason it has gone slowly, I think, is the widespread professional assumption that the very idea of recycled sewage would be repugnant to the public and would encounter a massive wall of resistance. I'm sure this belief led many innovators to tread very gingerly when otherwise they would have forged ahead boldly.

Yet I went down to one of the first experimental projects of this sort at Santee, Calif., and talked to mothers while their children splashed happily in a crystalline pond made of reclaimed sewage. I said to them, "Do you have any strange feelings or misgivings about your children swimming in refined sewage?" Unanimously, the answer was, "No, why should we think about that? Anybody can see that that water is as clean as can be."

This, as far as I know, has been just about the universal reaction to wastewater reclamation. The anticipated acceptance barrier, like the imaginary sound barrier in aviation, proved not to be there at all. This is one small example of how thinking in the language of your constituents can be very important in accomplishing what you want to do.

Please understand, I'm not venturing to picture the public as a bunch of nitwits whose primitive prejudices have to be manipulated like the keys of an organ. After all, they are your constituents, and without them, you wouldn't be where you are.

But at the New York Times, we have an unwritten precept, and that is when you write a story imagine that the person reading it just got out of a prisoner of war camp yesterday. The individual is reasonably bright, but put all of the facts in there necessary to make it intelligible to the reader without the reader's having to comb through any back issues.

In other words, don't underestimate people's intelligence, but never overestimate their information. Thousands of impressions from many sources crowd into every citizen's memory bank every day now, at a greater rate than ever before in history. Anyone in a specialized field who assumes that the public knows what he or she is talking about probably is wrong.

What does this mean in terms of the large-scale effort in government, science, industry, conservation, to firmly establish the integrity of water? I think what it means is that it calls for one of the biggest public educational campaigns in history. Not the sort of thing that can be done with a fanfare of trumpets and some WIN buttons and is forgotten about in a month. But a concerted long term effort on the part of every person in the field who wants to see his or her efforts get the financial and moral support that they have to have.

The inclination of many professionals is to say: "Well, I'm a professional, I'll just do my little professional thing, and leave the educational work and propaganda to professionals in that field."

If I can leave only one thought with you today, it is that that outlook won't wash anymore. In these days of instant communication, everyone has to tell his story, or do what he can to help along the cause of enlightenment, because there is so much enlightening to be done.

No man is an island anymore. The sheepskin on the wall saying you are some kind of a specialist doesn't mean you can isolate yourself from the people who underwrite your work. When they count the votes that support appropriations, sheepskins don't get counted.

This may seem like a very crass, materialistic outlook. It isn't. I think it's only realistic. Environmental problems today are 90 percent politics. We know immensely more technically than we can put into practice, because getting it into practice is dependent on the political process.

Those of you who work here in Washington know this. You are used to going up on the Hill to support what you are doing. But the same thing applies all over the country at all levels, right down to the village level. In the early days of air pollution control, for instance, Phoenix, Ariz., had one of the best air pollution engineers in the country. He got nowhere because he didn't realize that unless his technical ideas were translated into viable propositions in the political context, they didn't mean a thing.

Conversely, Los Angeles' air pollution director for years was a man who knew very little about the technology of air pollution. He was a former police lieutenant, Louis Fuller. But he knew how to go to the county politicians and get things done. An example of what he could do on this basis was that, single-handedly, he transformed the entire paint industry in this country, getting manufacturers to change their historic paint formulas, to eliminate certain objectionable solvents.

I think a great deal of water pollution in this country is probably traceable to sanitary engineers, the men who run the municipal sewage treatment plants. For years, they could foresee that their systems were being overloaded, so they sent memos up to City Hall saying the sewage plant should be enlarged. And when the politicians did nothing about it because there is no political glamour in enlarging a sewage plant the engineer went back to his drawing board and said, "Well, I have done my duty. I'm an engineer. If the politicians don't want to go along, that is their problem."

The trouble was, as we all know, it ended up being *his* problem, the engineer's problem. If he had gone to his constituents in as elementary a way as giving talks at Rotary Club luncheons, and familiarized the public with the problems he had, he would have helped generate the head of steam necessary for political action that would have made his job a lot easier today.

All right, so everybody isn't a William Jennings Bryan or a Ralph Nader, capable of galvanizing public action. That is not the point. The point is that everybody can do something, even if it is only spreading the gospel in conversation with friends. The important thing is awareness that the message has to be conveyed by any means possible—that there has to be communication with the constituents.

I can't, within this afternoon's format, give you a detailed blueprint on just how this tremendous job of adequately informing the American public on water quality should be done. It would take 6 months, and at least a six figure fee, to lay out a campaign like that. A lot of the pieces of such an effort already are being done by information specialists in the EPA. But obviously this effort overall nationally, up to now, has not been comprehensive enough, when it takes years of grunting and groaning to get through an elementary piece of drinking water legislation; when the Coast Guard is still backing and filling about toilet tanks on pleasure boats, and chickening out on telling Onassis to put double bottoms on his tankers. And when some people equate clean waterways with unemployment.

With adequate public understanding of water problems sophistry peddlers like these wouldn't dare stick their heads out of the woodwork lest they get chopped off.

My point is, there is such a big informational vacuum to be filled that everybody in the water field, if he knows what is good for him, has to get with the effort. Everyone should make for himself or herself an analysis of what he or she thinks are the big gaps in public knowledge related to his field. Then he should canvas the tools that are available for informing people. The tools are not just a mimeograph machine cranking out handouts. They include newspapers, magazines, books, pamphlets, radio, television, conferences, symposia, lectures, personal appearances, and even personal conversations. Somewhere in that spectrum, everyone can find a spot where he can do something.

Finally, there should be the realization that the audience you are addressing, your constituents, is not a uniform, faceless, homogeneous mass that can be aroused by words in mimeographed handouts.

There are different levels of knowledge, sophistication, and interest. Clem Whittaker, the Californian who virtually created the art of modern political campaign management, had a maxim that every voter was at least seven different people: He was a taxpayer, probably a homeowner, a parent, a churchgoer, a motorist, a veteran, probably a Rotarian or a member of some other association like that, and finally, a person with, probably, ethnic ties.

Whittaker said that in the course of a political campaign an appeal had to be made to each of these various manifestations of the same person; and that if this was done, you stood your best chance of success in the campaign.

Think about this—and it will multiply your leverage in developing public understanding of water integrity and water quality. When this understanding is deep enough and wide enough, the integrity of the water will be close to an accomplished fact. Between now and then, there is a lot of time, but I urge you to waste no time in taking advantage of that time. It will make your work easier, and the public happier and more supportive, and it will make our water better.

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