PROCEEDINGS OF
UNIVERSITY SEMINAR ON
POLLUTION AND WATER RESOURCES

Volume III 1969–1970

PROCEEDINGS OF
UNIVERSITY SEMINAR ON
POLLUTION AND WATER RESOURCES

Volume III 1969-1970

Edited by
George J. Halasi-Kun
Kemble Widmer
and
George W. Whetstone

COLUMBIA UNIVERSITY
in cooperation with
U.S. DEPARTMENT OF THE INTERIOR,
GEOLOGICAL SURVEY

The New Jersey Department of
Environmental Protection
Bureau of Geology & Topography

BULLETIN 72 - B

CONTENTS

INTRODUCTION

Regulation of water pollution has become one of the most serious problems of our society and has become a topic of national concern all over the world. One of the bitter ironies of the history of the human race is that water, the very symbol of life itself, should have been so closely and constantly associated with suffering and death. Not only too much water, like floods, or too little, like droughts, have killed untold millions, but also the quality of it, like water contamination, has been devastating in man's survival. Waterborne diseases, such as cholera, dysentery, hepatitis, and typhoid fever, have played a significant role in population control, and even in warfare.

The third academic year was devoted primarily to water pollution problems caused by the expanding population, urbanization, and industrialization, which phenomena resulted in enormous amounts of waste. The "Annual December Meeting in Washington, D. C." with the World Bank as host was a review of the world situation about these problems.

The Seminar also organized the "Conference on International and Interstate Regulation of Water Pollution - March 12 - 14, 1970 in New York City" in cooperation with Columbia University School of Law. More than four-hundred-fifty participants from all over the world attended the Conference, and the Seminar members delivered ten lectures. As one of the results of the Conference, three law students received scholarships to study water pollution problems abroad.

Finally, the editors of the Proceedings wish to express their appreciation to all members who contributed articles and lectures to foster the Seminar. Publication was made possible only by the generous help and cooperation of the U.S. Department of the Interior and the State of New Jersey Department of Environmental Protection.

George J. Halasi-Kun
Chairman of the University
Seminar on Pollution
and Water Resources
Columbia University.

WATER RESOURCES RESEARCH IN THE UNITED STATES

by

ROLAND R. RENNE, Ph.D.

Professor of Agricultural Economics and Associate Dean of the
College of Agriculture, University of Illinois
at Urbana-Champaign, Urbana, Illinois,
and formerly Director of the Office of Water Resources Research
of the U.S. Department of the Interior, Washington, D.C.

Only recently (since 1964) has the United States had a systematic, continuing, Federal-State cooperative water research program to increase available supplies of useable water and to attain more efficient water use. In 1964, the Water Resources Research Act was passed establishing such a program. In addition, the National Water Resources Planning Act was passed in 1965 to establish continuing, coordinated, comprehensive planning of water resources development and management with the States for all major river basins.

Also in 1965, and since, additional legislation has been passed including the Water Quality Act of 1965 and the Clean Water Restoration Act of 1966, to establish an effective Federal-State water pollution control program with authority and funds to provide and enforce water quality systems in order to prevent further pollution and to clean up existing pollution. Finally, in September 1968, the National Water Commission was created by Public Law 90-515 to undertake a five-year study of water resources problems leading to policy recommendations to guide future activity in water-related fields.

This legislative package makes possible the solution of many of our more serious water problems, but in and of itself, it does not assure the problem solving. To achieve significant increases in useable water supplies and the more efficient water use so badly needed, a greatly expanded water resources research program is vital.

The Importance of Research

Research is basic to effective planning and sound development of our water resources. Without a strong research effort, both basic and applied, the possibilities and probabilities are greatly diminished for overcoming our perplexing water problems.

Scientific research is the underpinning upon which technological innovations in resource use and development depend. Policy in turn is shaped principally by what development and use, practices and controls, are possible with current technology. Where crash programs are necessary to meet critical or disastrous conditions growing out of continued abuse of resources and lack of proper use and management practices, of which our water resources are a good example, policies may be determined first along with action programs to implement the policies, with the needed research and technology following, rather than preceding, the policy-making process. The latter, of course, is the more desirable and sound procedure, but by no means always used. This is especially so in the case of our water resources.

Growth in our economy and restoration and improvement of the quality of our environment can come only from change. Innovation in technology, through implementation of change in an organized activity, is a major component of the force that has shaped our economic growth.

Scientists and engineers, working in organized research and development projects are the principal source of new technology. In earlier times "tinkerers and geniuses" accounted for a significant portion of inventions and innovations. Today, however, though research is supported by State governments, foundations, and industry, the major share is financed by the Federal Government.

Our Research Goals

Current dominance of Federal support for research and development has increased interest in the process of technology transfer and use. Only two or three decades ago, most organized research and development were privately financed, and were directed toward profit-making innovations. Today, however, under our large Federal programs, economic criteria govern only a small part of our research and development efforts. Now they are aimed at much broader and more diverse objectives such as national security, health and welfare of the people, space activities, efficicacy of the educational system, restoration and improvement of the quality of our environment for better living, beauty for America, continued growth of the economy, and other avowed goals.

Federal research and development funds today make up two-thirds of the total research and development expenditures of the Nation, and have increased an unbelievable 230-fold since 1940 (slightly over a quarter of a century). In 1940, only $74 million, or eight-tenths of one percent of a $9 billion Federal budget, was spent on research and development compared with about $17 billion, or about 12.6 percent of a $135 billion budget, in 1968. The amount of dollars for research and development is about the same for the current 1970 fiscal year as for 1968, but the $17 billion comprises a considerably smaller percentage of the considerably larger total Federal budget--less than 10 percent.[1/]

About $12 billion of the $17 billion Federal expenditures for research and development, or about 70 percent, are spent for development of new technology oriented principally to the specific mission of the defense and space agencies. This leaves about $5.2 billion for all other research and development activities.

It is particularly significant that in the past decade the research portion of total Federal research and development expenditures has increased from 21 percent in 1959 to 38 percent today, or from approximately one-fifth to two-fifths in the decade. This would tend to indicate that the Federal Government is making a special effort to anticipate and prepare for the accelerated change situation of the country since scientific research is basic to effective planning and sound resources development. This assumes that a major share of the research effort is devoted to the more important problems of our time. The key to effective adjustment to change is the relevance of research undertaken to aid in solving major critical problems.

1/ Data on Federal expenditures for research and development were secured from Special Analyses, Budget of the U.S., published annually for fiscal years, U.S. Government Printing Office, Washington, D.C.

Research Trends

About two-thirds of the total Federal research expenditures go to support physical sciences, one-fourth to support life sciences and the remaining 7 percent to support social and other sciences. Many contend that too little is being spent on the social and other sciences. In absolute amounts, the expenditures for social science research are relatively small but since 1956 they have been increasing at a greater rate than expenditures for the physical and biological sciences. Support for the social and psychological sciences has increased at an annual growth rate of 26 percent, compared with 20 percent for the physical and biological sciences.2/ However, the 26 percent increase in the social and psychological sciences is not a large absolute increase because the base on which the percentage increase is computed is small compared with that of the physical and biological sciences.

Currently, Federal programs are placing increasing emphasis on education and social adjustment, on urban and metropolitan living conditions and area development, and on the total behavior and life of man. Many contend that in view of these trends, the social sciences will continue to show a sharp rate of growth. At the same time, however, emphasis is being placed on atmospheric sciences, on marine science and technology, on space programs, on water resources supply and quality management problems, and on biometrical research, all of which emphasize multidisciplinary effort, but draw heavily on the physical and life sciences.

It is obvious that Federal expenditures for research and development cannot continue to increase indefinitely at the same rate they have increased the past quarter of a century. In fact, they have already leveled off at around $17 billion a year and now comprise a significantly smaller percentage of the total Federal budget than a short time back. However, there may be, and no doubt should be, significant changes in the distribution of research and development funds for various purposes to meet the Nation's changing needs. This would result in significant increases for some purposes, no increases--or actual decreases--in others.

Although the immediate situation is cloudy and uncertain because of fiscal problems associated with our current domestic difficulties, and our heavy worldwide obligations and defense expenditures, it seems logical to conclude that over the longer term there will be increased expenditures of Federal and other funds for research in those fields where serious problems exist, increase, or persist, including the social and psychological disciplines as well as the physical and biological sciences. Serious U.S. water problems exist, and are increasing; and many will persist for a long time. They would seem to qualify by their very nature

2/ See Federal Funds for Research, Development, and Other Scientific Activities, Surveys of Science Resources Series, National Science Foundation, published annually, U.S. Government Printing Office, Washington, D.C.

for a strong scientific research effort involving the social and psychological, the physical, and the biological sciences, and in addition a considerable multidiscipline research effort.

The U.S. Water Research Situation

In view of the above facts and observations, what is the current water research situation? How much of the total Federal research effort is devoted to water problems? Is this amount adequate to provide the scientific knowledge essential for satisfactory solution of our more serious water supply and water quality problems for the next two, three, or four decades? What are our most serious water research needs today? Which are being most adequately met and which least or most neglected?

About 2 percent of the total Federal research expenditures are currently used for research on water problems. Following passage of the Water Resources Research Act of 1964, the Water Resources Planning Act of 1965, the Water Quality Act of 1965, and the Clean Water Restoration Act of 1966, appropriations for water research increased sharply. In fiscal year 1964, Federal expenditures for water research were $65 million. In 1965 they were $70 million; in 1966, $88 million; 1967, $117 million; 1968, $124 million; 1969 (estimated), $130 million; and estimated expenditures for fiscal year 1970 (July 1, 1969, to June 30, 1970) are $133 million.

The above figures show that there was an increase of $47 million for water research in the two years 1965 to 1967 or an average yearly increase of $23½ million. The increase for fiscal year 1968 was only $7 million over 1967, an increase of only $6 million in 1969 over 1968, and an estimated increase of only $3 million for fiscal year 1970 over fiscal year 1969. Thus, the indicated increase for the three years 1968-1970 of $16 million is only approximately a third of the $47 million increase for the two-year period 1966 and 1967, and thus, water research expenditures, although increasing, have been increasing at a greatly reduced rate since fiscal year 1968.

The Water Resources Research Committee of the Federal Council for Science and Technology in its 1966 report "A Ten Year Program of Federal Water Resources Research"[3/] recommended that the Federal water research effort be stepped up from $70 million, the fiscal year 1965 level, to approximately $200 million in fiscal year 1971. The estimated water research expenditures for fiscal year 1970 of $133 million is, therefore, some $67 million below the recommended fiscal year 1971 level. To attain the recommended 1971 target would require an increase of 50 percent over the fiscal year 1970 level. This means that only half the recommended increase

3/ A Ten Year Program of Federal Water Resources Research, Federal Council for Science and Technology, Committee on Water Resources Research, Office of Science and Technology, U.S. Government Printing Office, Washington, D.C., February 1966.

was attained in the first four years of the five year period fiscal year 1966 to fiscal year 1971. The prospects that this 50 percent increase in fiscal year 1971 will be attained are not very bright at this time.

In this author's opinion, the present rate of Federal support for water research will not be sufficient to enable us to meet our needs for adequate supplies of good quality water twenty to thirty years from now. Only one of the nine major categories of water resources research4/ is now securing as much funds as the level recommended by the Committee on Water Resources Research for this year. This is category III, "Water Supply Augmentation and Conservation." This is attributable to the heavier than expected expenditures for saline water conversion.

Is 2 percent of Federal research expenditures a reasonable share for water research? How can we determine reasonableness? One way is to compare the amount spent for research with the capital investment in water resources development. The national (Federal, State, local, and private) investment in water resources plant and facilities is about $14 billion yearly. The estimated long-term investment in urban water supply and waste water (sewers and pollution control) facilities alone is over $90 billion.5/

Thus, the current rate of annual expenditures for water research is less than one percent of the yearly investment in water facilities and plant. This seems like a very small amount and a larger expenditure for research would appear to be justified, even with a very small portion of the research effort being productive of useful results. Annual new investment will be increasing each year as urbanization spreads, as efforts to control water pollution expand, and as municipal, industrial, and other water resource developments are authorized to provide for the needs of a growing nation.6/ This would indicate that water research should be increased now to provide the needed knowledge necessary for improved technology for these future water resource developments.

4/ The nine categories are: I Nature of Water, II Water Cycle, III Water Supply Augmentation and Conservation, IV Water Quantity Management and Control, V Water Quality Management and Control, VI Water Resources Planning, VII Resources Data, VIII Engineering Works, and IX Manpower and Grants. See Ten Year Program of Federal Water Resources Research, Federal Council for Science and Technology, Committee on Water Resources Research, Office of Science and Technology, U.S. Government Printing Office, Washington, D.C., February 1966.

5/ See Federal Water Resources Research Program for Fiscal Year 1969, Federal Council for Science and Technology, Office of Science and Technology, Executive Office of the President, U.S. Government Printing Office, Washington, D.C., August 1968, Foreword, p. vi.

6/ Ibid.

Major Water Problems

We are currently using* only a fourth of our annual available fresh water supply and actually consume* only one-fifteenth of it. Our water demands are increasing, with 1980 demand expected to be double that of 1960, and demand in 2000 triple, but our overall supply is still expected to be considerably in excess of demand. Nevertheless, the United States has serious water problems and they are becoming more serious.

There are six major water problems that plague different parts of the Nation. These are: (1) inadequate supply, (2) pollution, (3) uneven distribution, (4) floods, (5) variability of both supply and demand, and (6) chemical and sediment problems. Every part of the U.S. has at least one of these, some have several, and southern California has all six. But no two areas have precisely the same problem or problems, or to the same extent.

For example, the Southwest has the most acute water supply shortage, the Great Lakes region and the eastern seaboard the most serious manmade pollution problems, the Upper Missouri Basin and the Southwest the most serious chemical and sediment problems, the Great Plains the most variable supplies, the Northwest and certain parts of the Midwest the most serious flood problems, and much of the area west of the 100th meridian has serious distribution problems.

The Senate Select Committee in its 1961 report concluded that full development of all available water resources in 5 of the 22 major water resources regions will be required by 1980, or earlier, and in three additional regions by the year 2000, if projected population increases and economic activity are to be achieved.7/ The five are: the South Pacific area (southern California largely), the Colorado River area, the Great Basin (the Nevada-southern Utah area), the Upper Rio Grande-Pecos River area, and the Upper Missouri River area. The first four of these are in the Southwest. The three regions added for the year 2000 are: the Upper Arkansas-Red River area, the Western Great Lakes region, and the Western Gulf area.

Stated in grossly oversimplified form, our overall national water problem is one of getting the right <u>amount</u> of water, of the right <u>quality</u>, at the right <u>time</u>, at the right <u>place</u>, at a reasonable <u>cost</u>. In spite of our

---

* When water is "consumed" its form is so changed that it is not available for further use. Agriculture is the largest "consumer" of water because much water is absorbed into the plants and is not available for other uses. In water power generation, on the other hand, water is still available for further use after being run through the generator since it may need only to be cooled.

7/ <u>Report of the Senate Select Committee on National Water Resources</u>, U.S. Senate Report 29, 87th Congress, 1st Session, 1961.

overall abundance of water, this is not a simple, easy-to-solve problem. It is one of the most complex and difficult we face.

What we do about our water problems between now and 1980 and 2000 will determine to a great extent whether they will be less or more serious, or about the same as currently. Our haste, waste, and tastes have created a great many of our water problems. More specifically, pollution, complacency, inadequate planning, limited research, uncoordinated development programs, wasteful use, inadequate facts, and poor management are among the most serious causes.

If widespread, continuing concern and vigorous action replace complacency, increased research to provide more adequate scientific knowledge for improvement of technology replaces ignorance, prudent use replaces waste and neglect, and wise planning and good management replace lack of effective planning and management, our water problems in 1980 and 2000 can be less serious than now.

There are at least eight general approaches to solve water problems. These include: (1) improved treatment of wastes to make water usable; (2) reuse--treatment or "laundering" after each major use to permit a further reuse; (3) restricted use through metering or progressive charges to discourage waste and uneconomical use; (4) use classifications for water with a quality grade or standard consistent with the quality required for a given use; (5) improved management of watersheds to catch and hold water to increase water recharge; (6) desalination; (7) weather modification; and (8) importation from areas close by or farther away.

The first five, and especially the first two, have proven effective in varying degrees in different areas over the years. The extent of their application has been influenced by costs of alternative sources of supply, tradition, and institutional considerations, state of knowledge and technology, and quality of management.

Together, these five, singly or in combination, can enable needs in many areas to be met for the next 10, 20, or 30 years, but their costs may increase significantly if their use is greatly increased. This will tend to limit further extensions in the future. In addition, technical, political, and legal factors may prevent unlimited application. In areas where water supply and quality problems are most acute, any one or more of these five approaches may not provide adequate solutions. The other three approaches--desalting, weather modification, and importation, singly or in combination, may provide the needed quantity and quality of water. In a physical sense, these three could supply almost unlimited quantities, but to date economic feasibility and/or technical problems have definitely limited their use. Much more research is needed to solve both the economic and technical problems involved. Considerable progress has been made recently, which is encouraging. With importation, either interbasin transfers or international importation, political feasibility is an additional very difficult problem to solve.

Current Water Research

There has been a marked increase in the amount of water resources research in the past five years, growing out of recent national legislation which authorizes such research and funds for it. The extent of the increase is reflected in part by the number of water resources research projects currently under way compared with a few years earlier.

Although all research projects are not recorded in the Science Information Exchange of the Smithsonian Institution in Washington, D.C., the most complete data are available from this source. The Office of Water Resources Research in the Department of the Interior contracts with the Science Information Exchange to publish catalogs yearly showing all water research projects under way.

The first catalog was published in 1966 and listed all recorded current water resources research under way in 1965, whether federally or non-federally supported. There were about 2000 such projects. Three years later the 1968 catalog listed approximately 4200 projects, or more than double the 1965 number. In 1969, more than 4500 projects are listed.

Nearly three-fourths of recorded on-going water research projects are supported wholly or in part with Federal funds. More than 600 performing organizations are carrying out the research, of which 135 are Federal agencies and the remainder (471) are comprised of State and local government agencies.

The emphasis in these projects is heaviest on water quality management and protection, one of the nine major water research categories cited earlier. Approximately one-third of all current water resources research projects recorded deal with some aspect of water problems in this category. These include identification, fate, and effects of pollutants; waste disposal; waste treatment processes; water treatment; and water quality control. The number of projects dealing with these problems has increased five-fold since 1965, reflecting the focus on these problems through establishment and funding of the Federal Water Pollution Control Administration by the Water Quality Act of 1965 and the Clean Water Restoration Act of 1966.

The second largest type of water research being currently undertaken throughout the Nation deals with aspects of the water cycle. These include precipitation; snow, ice, and frost; evaporation and transpiration; streamflow; groundwater; lakes, erosion, and sedimentation; chemical processes; and estuarine problems. More than one-fourth of the total recorded projects deal with these water cycle aspects and reflect a three-fold increase since 1965.

The third largest type of water research under way deals with water resources planning problems. These include techniques of planning; the evaluation process; cost allocation, cost sharing, pricing, and repayment; water demand; water law and institutions; non-structural alternatives;

and ecologic impact of water development. Currently over one-eighth of the total projects recorded deal with these water resources planning problems and reflect an increase of about one and a half times in the number of these projects since 1965.

All of the nine major water research categories except one show increases in the number of projects in operation now compared with four years ago, but over two-thirds of the total increase is accounted for by the three categories: water quality management and protection, the water cycle, and water resources planning. The one category that did not show an increase in number of research projects is water supply augmentation and conservation, which includes saline water conversion, water yield improvement, use of water of impaired quality, and conservation in domestic use, in industry, and in agriculture. The number of projects in this category declined by about one hundred during the past four years.

Relatively small increases in number of research projects occurred over the four-year period in the five remaining major water research categories: (1) research in water engineering works covering design, materials, construction, and operation; (2) research in water quantity management and control covering control of water on land, groundwater management, watershed protection, and effects of man's activities on water; (3) research on the nature of water, including water properties, aqueous solutions and suspensions; (4) research in water resources data involving network design, data acquisition, evaluation, processing, and publication; (5) research grants and contracts for manpower and facilities.

The impact of the heavy emphasis currently placed upon research in water pollution problems, in problems dealing with the hydrologic cycle, and in research essential for effective planning and development of water resources programs and projects, should become increasingly apparent as we continue to deal with our water problems throughout the United States. At the present time it would appear that this emphasis (two out of every three available water research dollars) on these three research categories would continue with relatively minor changes at least for the next three to five years or longer, if we are to secure the kind and amount of scientific knowledge we must have to solve our most serious water problems.

Priority Water Research Needs

Exactly what should be the allocation of available research funds among the several above-mentioned subcategories of the three major research categories together involving two-thirds of the total current water research projects? And what allocation should be made to various subcategories in the other six major categories? This is, of course, very difficult to say. Undoubtedly there will be significant budget adjustments from time to time for numerous reasons. The following discussion is designed to provide some guidelines by pointing up what appear to be currently relatively high priority research needs.

First of all, it appears to the author that it would be helpful to concentrate on perhaps five major solution approaches to our water problems. The five suggested are: (1) improved and increased waste treatment; (2) recycling or "laundering" after each major use for one reuse or several usings; (3) desalting; (4) weather modification; and (5) importation from nearby or far away.

In each of these five approaches the economic considerations are highly important and often critical. The first two--waste treatment and reuse--are traditional approaches to increase the supply of useable water. Therefore, the first priority research need is to secure a more complete understanding of the performance, potential, and limitations of possible methods of pollution control. Aspects needing much research include: recovery and reuse both of the used water and of the pollutants; modification of contaminants in waste, and their removal and disposition; product modification by introducing pollution-reducing properties into potentially contaminating materials; modifying contaminant-using processes to prevent or reduce release; preventing contaminant from entering the environment; removing pollutants or diminishing their effects.

Another important research need is improved instrumentation for detecting specific pollutants. Some 240 water pollutants have been identified by the Federal Water Pollution Control Administration. High reliability, low-cost automatic instrumentation is needed for determination of odors, physical properties of aerosols, hydrocarbon reactivity, etc. There is a need for standardization in sampling methods to ensure amply comparable data from place to place.

Other important research needs include: (1) improvement of information on the effectiveness of various legal, administrative, and other means for giving effect to water resources management programs; (2) improvement of information on the water-environment-human use interactions, with special attention to: (a) water resources management in metropolitan environments; (b) water quality protection in groundwater aquifers, estuaries and lakes; (3) improvement of methodology for management of complex water systems with special attention to: (a) conjunctive surface groundwater management; (b) management of water supply augmentation by reuse, desalination, and other water salvage methods; (c) flood damage hazard mitigation by systems of runoff retardation, reservoir storage, channelization, levees, flood plain zoning, flood proofing, etc.; (d) marsh and wetlands management.

The almost complete lack of research in support of Government-wide, comprehensive planning is a major problem. In this area, our research objective should be not only improvement in the methodology and criteria for water resources planning, but also determination of the kinds and precision of information needed and the analyses relevant to evaluation of alternatives. Research in these areas should be increased markedly, as should research on institutional and legal arrangements for facilitating the results of more effective planning.

No sound approach to U.S. water problems is possible without an appreciation and understanding of benefits and alternatives. Consequently, research into cost allocations, cost sharing, pricing, and repayment should be greatly increased. The Congress has included recreation in its benefit-cost ratio legislation for water development projects, and research is needed to establish more adequate evaluations of recreational costs and benefits. Nonmonetary benefits are growing in importance, and a great challenge to researchers is the development of an effective way of including nonmonetary benefits and non-market-determined values of water resources development in the decisionmaking process.

Research is needed on the problems associated with multiple jurisdictions and conflicting objectives in metropolitan and regional water resource planning and management. Research results would be useful in providing a basis for improved mechanisms for water resources management with a view to improving management effectiveness through lessening of conflicts, uncertainties, and confusion among resource claimants.

Research is needed to develop indicators or other means for determining and predicting ecological changes, both of short- and long-term significance, occasioned by water resources development projects. Research findings will be useful in establishing criteria for planning, construction, maintenance, operation, and use of water resource development projects.

Benefit-cost analysis of public investment programs ranks projects and programs only in terms of economic efficiency. Research is needed to determine appropriate alternative social objectives and to develop methods to evaluate the benefits in relation to costs for the different objectives, such as alleviation of poverty, improved distribution of population, environmental quality, and other social values.

The above list of important U.S. water resources research needs is by no means a complete one. Only a few of what the author considers most important or high priority are included. More complete lists of studies that might be considered desirable, but not necessarily top priority needs, are available. One of the most recent is the May 1, 1969, tentative list of the National Water Commission.[8/] This list includes 31 possible studies, which, according to the covering statement of the Commission, have been prepared to help it accomplish its assigned task, which is to make a five-year study of water resources problems leading to policy recommendations to guide future activity in water-related fields in the United States.

The author has selected ten of these to show the nature and scope of coverage proposed by the Commission's studies. These are:

8/ Tentative Program of Studies Under Consideration by the National Water Commission, Mimeographed, 5 pages, Washington, D.C., May 1, 1969.

(1) Projection of regional water use and water problems for various sets of assumptions as to technological developments, population, distribution of population, growth of metropolitan centers, national economic goals, environmental objectives, the price of water, and other pertinent factors. (This study will be carried out in collaboration with the Water Resources Council, and the projections will be made to the extent feasible through the use of regional models.)

(2) Study to determine the relative productivity of water uses in various regions: The results to be used in (a) judging the efficiency of present water uses and programs, (b) formulating recommendations for the improvement of water uses and programs, (c) revealing areas in which economic development could be accelerated, at a justifiable cost, by augmentation of water supply or by more intensive development of the present supply, (d) evaluating proposals for transfers of water between basins, and (e) carrying out other studies to be undertaken by the Commission.

(3) Study of the various ways in which expected future water demands may be met: This study to encompass (a) means for making the most of the available supply by the encouragement of more efficient utilization practices, by metering, by the application of rational pricing policies or other economic incentives, by minimizing the pollution of the natural supply, and by treating and reusing polluted waters; and (b) means for increasing the supply of water now available to selected regions by desalting, by weather modification, by development of underground supplies which are not being utilized to the optimum extent, or by importation from other regions--either within or outside of the United States--and by further development of the native supply.

(4) Study of the water problems of typical metropolitan regions of the United States, including the problems resulting from: (a) the necessity for importation of water from distant river basins and the consequent need for regional water supply systems, (b) the increasing magnitude and difficulty of waste disposal problems, (c) the need for efficient regional planning institutions, (d) the need for the integration of water supply, waste disposal, and related programs into a comprehensive and unified program for the metropolitan region, and (e) the need for coordinating mechanisms capable of insuring that all local, State, and Federal programs (including grant-in-aid programs) are directed toward the goals of a unified program for the region.

(5) Study to provide a basis for recommendations on the policies and actions necessary to preserve the water storage sites that will be needed in the future.

(6) Survey of the State and Federal water laws related to surface, subsurface, and atmospheric water, and water quality: This survey to result in a syllabus of water laws especially designed for the use of the National Water Commission; a brief narrative discussion of basic differences

in State water laws; a comparison of Federal and State water laws calling attention to any important incongruities and the problems created thereby; an appraisal of existing laws from the standpoint of achieving optimum utilization of the water resource; a discussion of the legal problems involved in the transfer of water between major basins and its importation from other nations; and such other legal problems as the National Water Commission may specify.

(7) Study of the effects--both adverse and favorable--of water resource management and development activities upon the environment, including its impacts upon scenic beauty, historic and wild areas, fish and wildlife resources, recreational opportunities, and related values.

(8) Study of the efficacy of the existing water resources research program, and of the available basic data, from the standpoint of developing techniques for making the most of the Nation's water resources.

(9) Development of improved methods for the economic evaluation of contemplated water resource developments; giving special attention to the evaluation of secondary benefits, the discounting of long-deferred benefits, the period of evaluation, the amortization of costs, and the evaluation of recreational benefits. This study to take cognizance of the results of the study already under way by the Water Resources Council.

(10) Study to evaluate the effectiveness of water resource development as a means of inducing economic development in underdeveloped regions, including its effects on income distribution.

Concluding Thoughts

We have an enormous "deferred performance" accumulation in the field of water resources research. We are running a serious risk of "too little too late" in terms of the scientific knowledge and new technology needed to deal effectively with our growing water problems. In certain areas, the problems seem almost hopeless because we have let conditions worsen to such a serious point. There are, however, encouraging signs of progress and ultimate success. The almost unlimited achievement possibilities of modern scientific research and technology are powerful offsets to despair.

The total supply of available water is fixed, but the supply of useable water is not. There is a large spread between the two that provides ample opportunity to apply our best talents in achieving sufficient useable water for all our needs.

Water resources should be an especially rewarding field for productive research for years to come. The problems are of sufficient complexity, scope, and distribution to use fully the science and technology we can develop. The entire research community, including a large number of our universities and colleges, should find water resources problems a challenging field and can have a highly important role in determining the ultimate success of the three-way program--research, planning and development, and water quality management--upon which the Nation has embarked.

SEASONAL SEDIMENT YIELD PATTERNS OF UNITED STATES RIVERS

by

LEE WILSON, Ph.D.

New York, New York

The sedihydrogram (SHG) is a double-log plot of mean monthly sediment yield against mean monthly water yield. A line connecting consecutive months indicates the seasonal rhythm of erosion and runoff occurring in a drainage basin. Sediment regimes seen on the SHG are explained by a model which relates basin hydrology to the dominance of common air masses. Mediterranean and continental climate and erosion regimes are well expressed in United States rivers.

Mediterranean regimes in the western U.S. have a dry summer, wet winter, with strong seasonal contrasts between early wet season floods and less turbid flow events later in the wet season. It appears that maximum sediment yield values may be expected from basins in which seasonal desiccation alternates with heavy rains.

Continental regimes in central and eastern U.S. have a large water yield event in late winter or early spring, with low sediment concentration. Summer storms produce high concentrations and a low water yield. The summer component of the SHG is dominant in dry regions, but is minor in humid areas where vegetation offers effective protection from storms.

Land use factors influence sedihydrogram patterns. Basins in eastern humid States have a SHG typical of arid regions if strip mining or urbanization has had an important effect on basin hydrology. Most climate regimes cause a seasonal shift in sediment-transport-curve parameters, so analysis of seasonally grouped data results in improved equations for relating sediment movement to environmental controls. Prediction of sediment yield also requires that separate consideration be given to those factors affecting runoff, and those affecting sediment concentration.

I. Introduction

Sediment yield is a function of many environmental factors, including climate, vegetation, land use, basin topography, lithology, soils, and human activity. The study reported here concerns the role of climate in determining both seasonal and regional variations in stream sediment transport. Although the environmental controls of erosion are complex, only simple and generalized results of this study can be presented in a limited amount of space.

For this research, I compiled virtually all of the published and unpublished sediment data for rivers in the United States, especially gaging station records. Data analysis is a problem due to the mediocre quality of most sediment information (Meade, 1969). Quality control was attempted by screening out all records based on less than five years of daily sediment discharge, and by rejecting all those rivers markedly affected by upstream regulation. Records from over 100 gaging stations passed this simple screening, but some data used by other workers were rejected.

Suspended sediment discharge values, in tons per unit time, were divided by basin areas, to give sediment yield, in tons per square mile per unit time. Water discharge was converted to the same units and termed water yield. No consideration was given to bed load or dissolved load, which together make up 20 percent or more of the sediment discharge of most streams.

The accepted data are interpreted as being a measure of all the factors controlling erosion and runoff in the areas upstream from where the data were obtained. The effect of one of these factors, climate, was analyzed in some detail, as outlined in the following pages.

II. The sedihydrogram

Analysis of sediment records involves many assumptions and difficulties and it turns out that semiquantitative graphical methods can give more useful results than are produced by statistical methods (Guy, 1964; Fournier and Henin, 1962). A new type of graph, termed a sedihydrogram, or SHG, gives a coherent picture of seasonal streamflow variations. Figure 1 shows the basic SHG grid, which is six-cycle double-logarithmic. On the grid are plotted mean monthly sediment yield (y axis) and mean monthly water yield (x axis). On this particular figure are plotted the 12 monthly data points from the Virgin River, Virgin, Utah. Each monthly point is based on the average of five years of record, but similar results were obtained for the much larger Virgin River basin, Littlefield, Arizona, where the record length exceeds 20 years.

For the points plotted in figure 1, mean monthly water yield values range from 8,000 to 36,000 tons per square mile. Using a scale at the top of the grid, it can be determined that this water yield represents a monthly runoff of 2-10 millimeters. Sediment yield varies between 8 and 500 tons per square mile per month. Using a scale at the right of the grid, it can be determined that the monthly denudation rate is between one-thousandth and one-tenth of a millimeter.

Diagonal dashed lines are placed on the grid to give values for suspended sediment concentration. For the Virgin River mean monthly concentration ranges from about 700 parts per million to over 30,000 ppm. The incomplete sedihydrogram in figure 1 is actually a type of sediment-transport graph in which sediment yield is plotted as a direct linear function of water yield, but with appreciable scatter of points.

Figure 2 is a completed sedihydrogram and shows a closeup of the 12 points plotted in the previous figure. A line has been drawn connecting consecutive months, from January, month 1, to February, month 2, through December, month 12, and back to January. This line can be followed to obtain a picture of the seasonal hydrologic rhythm in the Virgin River basin. There are three distinctive peaks or flood seasons on this SHG, and three low flow periods. Sedihydrograms for individual years show the same seasonal pattern, although, of course, magnitude and timing of the flow events can differ appreciably from the average.

Each spring there are high runoff, low sediment concentration events related to baseflow and snowmelt. Mean monthly sediment yield is less than 100 tons per square mile. Each summer there are very turbid flash floods in response to thunderstorms. Despite the limited runoff, sediment yields at this time exceed 300 tons per square mile per month. In early winter in some years, there are heavy rains which move in from the Pacific Ocean. When these rains occur, usually in December, there is a third flood season. Runoff and concentration both tend to be large, with values intermediate between the other two flood seasons. Sediment yield for December averages over 425 tons per square mile, the highest of the year, but this large value is partly the result of one storm event.

Just as each of the three high flow seasons shows unique characteristics, so also are the low flow periods different. For example, sediment yield in July is five times that in January, despite much less runoff in summer than in winter. It is quite clear that the hydrologic regime in the Virgin River basin changes markedly from season to season. Similar changes have been noted in nearby areas (see Croft and Goodwin, 1956; Beatty, 1968).

These seasonal changes are readily correlated to climatic conditions. The best model of climate classification and dynamics as applied to natural processes is that published by John Oliver (1970), based on earlier work by A. N. Strahler (1965). The Oliver model permits identification of air mass controls which determine climate dynamics on a month to month or season to season basis. Each of the high flow seasons in the Virgin River corresponds to a period when a particular air mass condition prevails. Without discussing the Oliver model in detail, one can summarize by saying that air mass interactions in the U.S. produce two distinctive climate regimes, mediterranean and continental, and hence there are two distinctive sediment yield regimes in this country.

III. Sedihydrogram for a basin with a mediterranean climate

The mediterranean climate regime occurs along the Pacific Coast where a cool-wet winter alternates with a very dry summer. Figure 3 shows a typical sedihydrogram from northern California, where runoff is appreciable during all months. Low sediment yield, essentially zero, occurs during the virtually rainless summer, and high sediment yields, exceeding 1,000 tons per square mile per month, are typical of the wet winter.

This extreme variability in monthly sediment yield occurs only in climates which have a pronounced dry season--when the protective plant cover and soil are desiccated. Such seasonal climates, including mediterranean and monsoon, produce much higher maximum and mean denudation rates than are found under more equable climates. The data I have collected, while inconclusive, suggest that in the western U.S. basins with the greatest contrast between wet and dry seasons usually have the highest sediment yields. However, the effects of factors such as slope steepness, erodibility of basin material, and land use are also important, and can mask the influence of climate.

Note in figure 3 that the line leading from summer months to winter falls considerably to the left of the line leading back to summer. This means that for a given water yield there is much more sediment carried in late summer and early winter than in other months.

Many studies can be cited in order to help explain why stream turbidity and erosion should occur so readily during the beginning of the wet season (Anderson and others, 1959; Krammes, 1965; Douglas, 1967; Williams, 1969; Fournier, 1967). Probably a key factor is the poor plant cover and desiccated soil condition which exists following the dry season. Such surface conditions make the soil vulnerable to heavy rains that occur as the wet period begins; landslides are also common as a result of these rains. As the wet season persists the plant cover improves, soil cohesion increases, and erosion is less.

Another factor is that readily moved material is eroded during the first major floods of winter, so later storms find less material available for transport.

IV. Sedihydrograms for basins with a continental climate

The second type of U.S. climate is continental and occurs virtually everywhere except along the Pacific Coast. Continental climates have a stormy, relatively wet summer. In central and mountain States winter is cold, and usually dry; overall the climate is subhumid to arid. In the east, winter tends to be milder and fairly wet, and the climate overall is humid.

Figure 4 shows two sedihydrograms from New Mexico, where the relatively dry continental climate prevails. The SHG on the lower right represents semiarid conditions and shows a double-peaked form. Sedihydrograms with two peaks are typical for most basins which have a continental climate. Sediment yield is at a maximum during the winter-spring melt or high baseflow season, and again during the summer storm season. There is far less water yield and hence a far greater sediment concentration associated with the summer peak. Table 1 summarizes these seasonal contrasts in the hydrologic regime of dry continental basins (see columns 2 and 3).

The second SHG in figure 4 is from a basin with a very dry climate. In such basins, the winter or spring flow event is minor, and poorly developed on the SHG. Summer flows are the dominant factor in determining sediment yield in these desert and subdesert basins. Sediment concentrations are very high, since aridity precludes a significant plant cover which would limit particle movement. The two sedihydrograms of figure 4 reveal a difference in total annual sediment yield, but this difference is due partly to nonclimatic factors.

Figure 5 shows two basins in Maryland, where a humid continental climate prevails. The solid line represents a basin dominated by agricultural land use. The two-peaked continental SHG is clearly seen. Limited data from humid basins with a completely natural plant cover suggests that the summer peak is absent for such basins, with all major flows occurring in winter and spring.

The solid line in figure 5 is a sedihydrogram in which dominant sediment-producing flows occur in winter or early spring. In humid continental river basins summer flows typically are subordinate (see Wolman, 1959). This contrasts with the dominance of summer flows in drier regions, as summarized in columns 3 and 4 of table 1. The contrast is especially noteworthy because summer rainfall has a far greater erosion intensity in the eastern U.S. than out west. Clearly, the summer plant cover provides significant protection of soil in the humid east. The cover also utilizes much of the available water, thus limiting summer runoff. The protective vegetation is further responsible for overall erosion rates being less in humid areas than in most basins in drier regions (Langbein and Schumm, 1958).

V. Other climatic conditions; land use

The preceding discussion has not mentioned all of the variations in sedihydrogram patterns which can be observed for U.S. rivers. A more complete discussion of these variations is given by Wilson (1971). The SHG of each river system is somewhat unique, but most U.S. rivers have a basic pattern conforming to those mentioned above. Some SHG's show the marked influence of hurricanes or rare storms. Others reflect the total dominance of snowfall and melt, with little effect of storms. In a few cases, particularly complex climatic patterns result in sedihydrograms with three peaks. The Virgin River (figure 2) is an example. The three flood seasons in this basin occur because the regional climate involves both continental and mediterranean climate regimes.

Virtually all SHG's show the influence of land use, and in some areas seasonal timing of land use practices controls the timing of sediment yield peaks. Analysis of sedihydrograms for midwestern States is often impractical because land use factors mask the influence of climate. The effect of land management can also be seen on the SHG. The best examples occur for many basins in the Tennessee Valley. When postconservation sedihydrograms are compared to preconservation graphs, it is clearly seen that management practices effectively lower sediment yield, concentration, and runoff, with maximum effect during the summer storm season.

The dashed line in figure 5 gives the sedihydrogram for a suburban basin near Washington, D.C. A similar SHG exists for a strip-mined basin in Kentucky. Note that summer flows are large and actually dominate the graph. Total sediment yield is much greater than that found in the nearby basin (solid line) where land use is largely agricultural.

It seems logical to conclude from figure 5 that it is the plant cover, or lack thereof, which is critical in determining seasonal distribution of sediment yield. The ground surface in an area undergoing suburbanization is often bare, as is the surface of a strip-mined area. The ground is thus hydrologically similar to that of a desert, with the result that sedihydrogram patterns resemble those found for naturally arid areas. As indicated in table 1 (columns 4 and 5), the most important differences occur in summer, the season when precipitation has maximum erosion intensity. For basins with a mediterranean climate, the most important effects of land use should be observed early in the wet period.

VI. Sediment yield prediction models

Accurate and reliable prediction of sediment yield variations is not now possible on a regional or temporal scale, except in a general way, or except for very small areas (see Wischmeier and Smith, 1965). As data quality improves, it may become possible to develop multicomponent models for predicting sediment yield values. Some suggestions are made here regarding the nature of these models. The suggestions are made based on sedihydrogram analysis, as outlined above, and based on regression analysis of climate and hydrologic data from many basins in the United States (Wilson, 1971).

It is clear that interpretation of sediment yield data must consider climate type and climate seasonality. Regional data must be segregated according to climate regime before any valid study of the data can be attempted. For example, the relationship between mean annual sediment yield and mean annual precipitation for 1,500 world basins can be at least partly understood when the available data are subdivided according to Oliver's climate classification (Wilson, in press).

A related concept is that the environmental controls of sediment yield change as the climate of a basin changes seasonally. Table 1 summarizes some of the seasonal changes for continental climates. For a given basin, quantitative analysis of hydrologic records is much improved when the data set is factored into seasonal components. For example, sediment transport curves using seasonally grouped values have lower standard errors and higher coefficients of determination than curves using ungrouped data. This confirms the work of Miller (1951), who clearly established the importance of the seasonal rating curve for estimating sediment yield.

A third concept of value for those interested in predicting sediment yield variations is that expressed by Langbein and Schumm in 1958. They observed that sediment yield variations result from combined variations in water yield and sediment concentration. Each environmental factor affects water yield and concentration differently, sometimes in ways which have an opposite effect on net sediment transport. As a result, the relationship between any environmental parameter and sediment yield tends to be complex and nonlinear. The regression analysis referred to above (Wilson, 1971) showed that it is easier to predict monthly variations in sediment concentration and water yield than it is to predict variations in their product, sediment yield.

Sediment yield values can be effectively estimated only when a variety of controlling environmental parameters are included in the prediction model (see PSIAC, 1969). The model must include nonclimatic as well as climatic factors. In my regression studies, the following climatically related parameters have proved most useful in predicting monthly values of sediment concentration, water yield, and sediment yield: total monthly precipitation; storm frequency, intensity, and magnitude; snow conditions; antecedent soil moisture; plant cover (as estimated from temperature and moisture variations). The quantitative value and relative importance of each factor varies from season to season, depending on the type of air mass that is dominant. A factor that is important in one season may have a different role or be unimportant in another season. Ultimately, it is possible to make general correlations between climate dynamics (air mass distributions) and regional and seasonal rates of erosion.

VII. Summary

The sedihydrogram, a double-logarithmic plot of mean monthly sediment yield versus mean monthly water yield, can be used as a tool in hydrologic and geomorphic studies. Qualitative analysis of sedihydrograms for U.S. rivers has shown that there are two basic seasonal patterns of sediment yield in this country. One occurs in areas with a mediterranean climate, the other in areas with a continental climate. The effect of land use on seasonal sediment yield can be seen on many sedihydrograms.

Prediction of sediment yield variations, both in space and in time, must consider climate type and seasonality, as well as a variety of nonclimatic factors. Each factor which affects sediment yield must be analyzed in terms of its separate effects on the components of sediment yield--water yield (runoff, sediment transport hydrology) and sediment concentration (erosion, ease of particle entrainment).

A model for classifying climates, developed by John Oliver, should prove very useful to geomorphologists interested in climate-process relationships. The model, not discussed in detail in this paper, permits identification of the air mass distribution patterns which determine climate dynamics. Each particular sequence of air mass influences produces a specific climate regime, e.g., mediterranean, continental, or others. Each regime in turn gives rise to a particular seasonal rhythm or pattern of erosion and runoff, and a characteristic type of sedihydrogram.

Acknowledgements

This research was supported by funds from Columbia University, through the Department of Geology and the Computer Center. Professors A. N. Strahler, R. W. Fairbridge, and John Oliver gave frequent advice and critical comments as the research progressed. A very large number of persons have supplied data, regional information, and useful references. Particular thanks must go to the staff of U.S. Government agencies: Geological Survey, Agricultural Research Service, Forest Service, Soil Conservation Service, Corps of Engineers, and Tennessee Valley Authority.

Appendix: units for measuring sediment yield

One unnecessary problem facing any study of sediment yield is that the available data are published in terms of a large number of units. Without discussing this problem in detail, it is sufficient to note that there is much support for converting all values of sediment yield (or denudation rates) into metric units. The most convenient unit is: cubic meters of sediment per square kilometer of drainage area per year ($m^3\ km^{-2}\ yr^{-1}$; or $m^3/km^2/yr$). One such unit, or 1 mky for short, represents a lowering of the drainage basin surface by 1 millimeter per thousand years, and 1 meter per million years.

One English short ton of sediment yield per square mile per year is equivalent to 0.132 mky, or a lowering of 0.132 millimeter per thousand years. This conversion assumes that the earth's surface rocks have a density of 2.65. One acre foot of sediment yield per square mile per year equals 476 mky, or a lowering of 476 millimeters per thousand years. Conversely, 1 mky of sediment yield equals 7.5 tons or 0.0021 acre feet per square mile per year.

It is hoped that the above conversions can be used in the effort to standardize units for reporting sediment yield and denudation rates.

References Cited

Anderson, H. W., Coleman, G. B., and Zinke, P. J., 1959, Summer slides and winter scour--dry-wet erosion in Southern California mountains: U.S. Forest Service Pacific Southwest Forest and Range Expt. Sta. Tech. Paper 36, 12 p.

Beatty, C. B., 1968, Sequential study of desert flooding in the White Mountains of California and Nevada: U.S. Army Natick Labs, ES-37, 96 p.

Croft, A. R., and Goodwin, V. O., 1956, Some flood characteristics of Sierra Nevada east fron watersheds: Proc. Tenth Nevada Water Conf., p. 12-17.

Douglas, Ian, 1967, Erosion of granite terrains under tropical rain forest in Australia, Malaysia and Singapore: Internat. Assoc. Sci. Hydrology Pub. 75, p. 31-39.

Fournier, F., 1967, Research on soil erosion and soil conservation in Africa: African Soils, v. 12, p. 53-96.

Fournier, F., and Henin, S., 1962, Étude de la forme de la relation existant entre l'écoulement mensuel et le débit solide mensuel: Internat. Assoc. Sci. Hydrology Pub. 59, p. 353-358.

Guy, H. P., 1964, An analysis of some storm-period variables affecting stream sediment transport: U.S. Geol. Survey Prof. Paper 462-E, p. 1-46.

Krammes, J., 1965, Seasonal debris movement from steep mountainside slopes in Southern California: U.S. Dept. Agricultural Misc. Pub. 970, p. 85-88.

Langbein, W., and Schumm, S. A., 1958, Yield of sediment in relation to mean annual precipitation: Am. Geophys. Union Trans., v. 30, p. 1076-1084.

Meade, R. H., 1969, Errors in using modern stream-load data to estimate natural rates of denudation: Geol. Soc. America Bull., v. 80, p. 1265-1274.

Miller, C. R., 1951, Analysis of flow-duration sediment-curve method of computing sediment yield: U.S. Bur. Reclamation, Denver, Colorado.

Oliver, J., 1970, A genetic approach to climate classification: Assoc. Am. Geographers Annals, v. 60, p. 615-637.

PSIAC, 1968, Factors affecting sediment yield and measures for the reduction of sediment yield: Pacific Southwest Inter-agency Comm. (U.S. Corps of Engineers), San Francisco, California, 24 p.

Strahler, A. N., 1965, Introduction to Physical Geography: New York, John Wiley and Sons, 455 p.

Williams, M. A. J., 1969, Prediction of rainsplash erosion in the seasonally wet tropics: Nature, v. 222, p. 763-765.

Wilson, L., 1971, Suspended sediment yield in United States rivers as a function of climate: Unpub. Ph.D. dissertation, Columbia Univ., New York, N.Y., 401 p.

______ in press, Variations in mean annual sediment yield as a function of mean annual precipitation.

Wischmeier, W. H., and Smith, D. D., 1965, Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: U.S. Dept. Agriculture Handbook 282, 47 p.

Wolman, M. G., 1959, Factors influencing erosion of a cohesive riverbank: Am. Jour. Sci., v. 257, p. 204-216.

Figure 1. Sedihydrogram grid with 12 mean monthly flow values for the Virgin River, Utah.

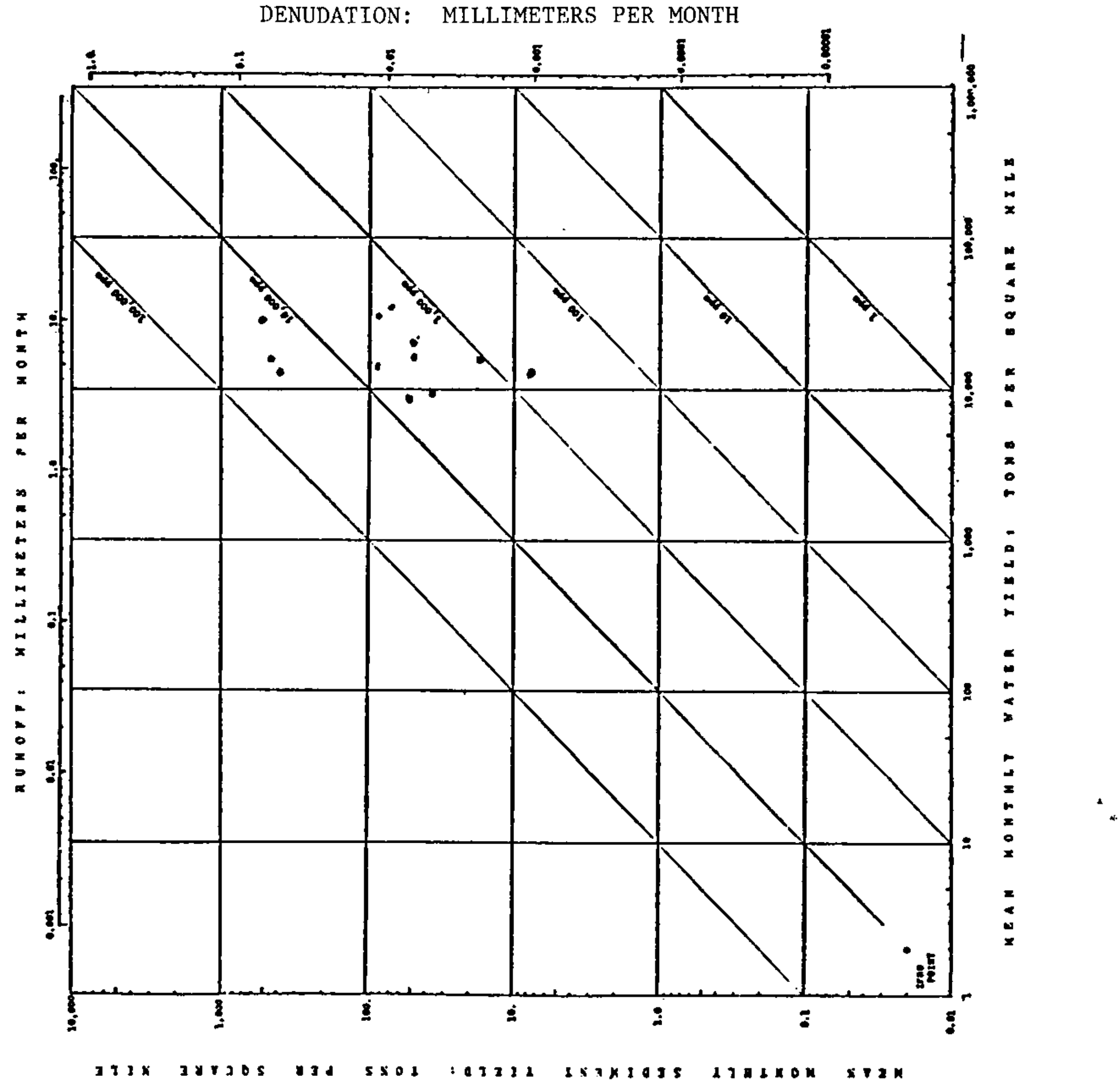


Table 1. Characteristics of different flow seasons in basins with a continental climate (in United States). Table concept taken from Croft and Goodwin, 1956.

Column 1	Column 2	Column 3	Column 4	Column 5
Characteristic	Winter, spring east or west	Summer, dry western U.S.	Summer, wet eastern U.S.	Summer, wet eastern U.S., suburb, strip mine or construction area
Soil moisture	Wet, little or no storage cap.	Dry, can store much water	Fairly dry, can store water	Dry, can store water
Precipitation type	Prolonged rain and/or snowmelt	Short intense thunderstorms	Many short intense storms	Same as column 4
Storm area	Affects large areas	Affects small areas	Same as column 3	Affects very small areas
Vegetation condition	Dormant	Much bare soil	Good cover	Much bare soil
Runoff volume	Largest of the year	Relatively small	Small, but more than column 3	Moderate to large; less than winter
Sediment concentration	Relatively small (often less than 1,000 ppm)	Relatively large (often over 10,000 ppm)	Always small (under 1,000 ppm)	Very large, often exceeds 10,000 ppm)

Figure 2. Completed sedihydrogram for the Virgin River, Utah. A line connects points representing flow values for consecutive months, i.e. the points of figure 1. The line reveals the seasonal hydrologic rhythm of the basin.

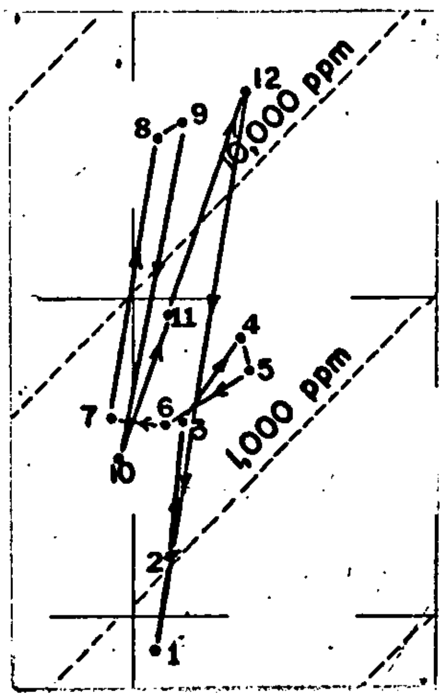
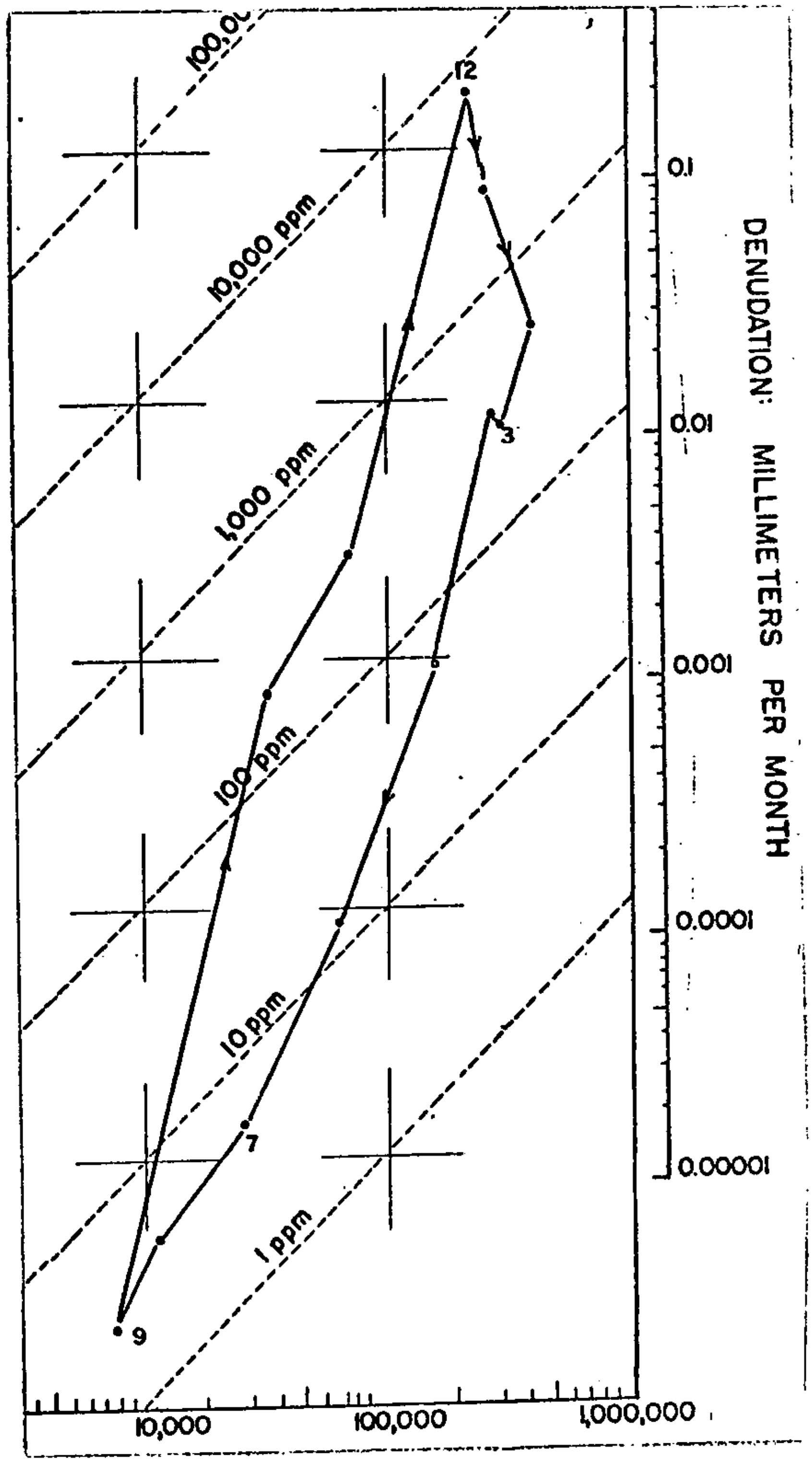


Figure 3. Sedihydrogram for East Fork Trinity River, California. (Errors exist in the scale along the bottom of the figure - please ignore).



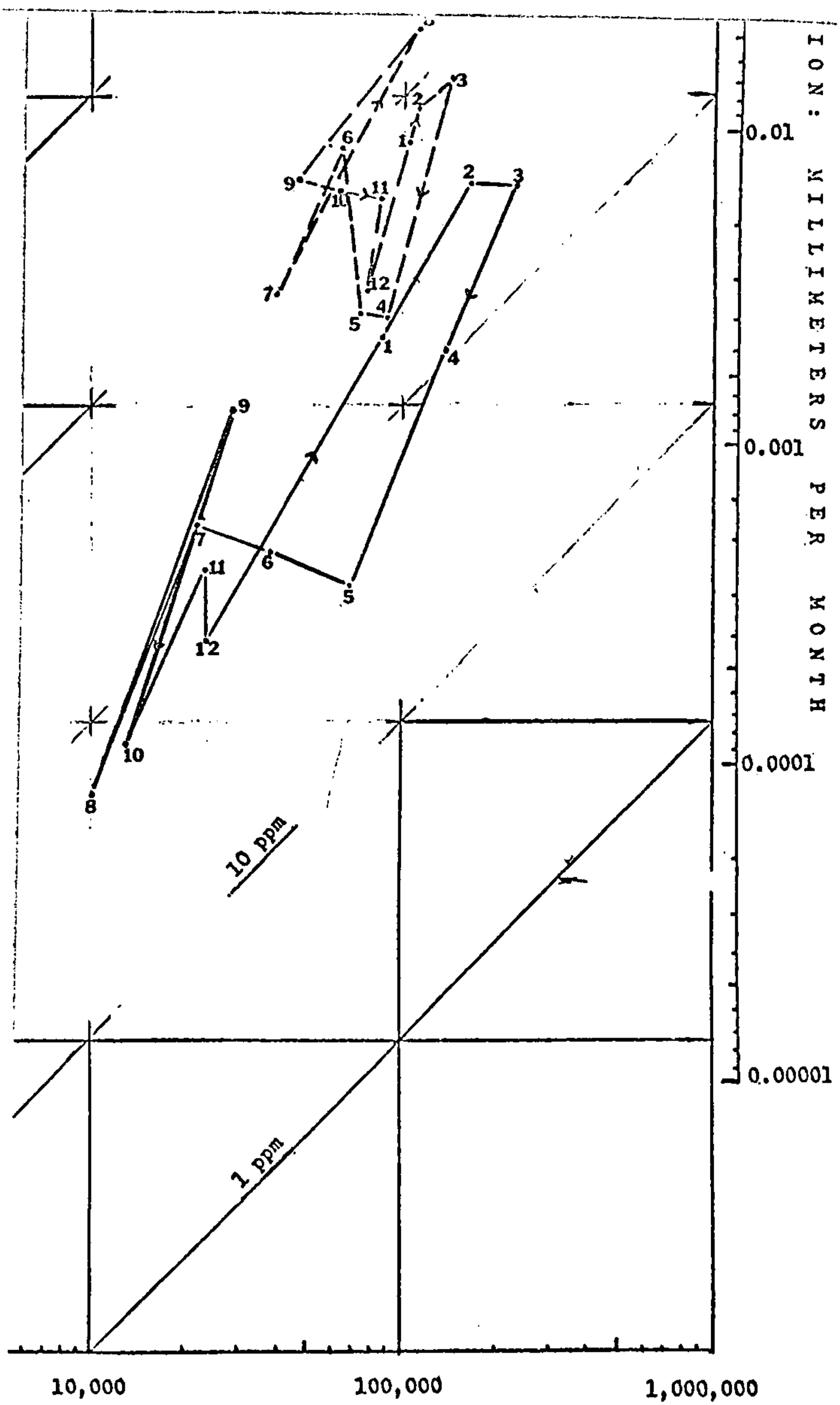


Figure 5. Sedihydrograms for Monocacy River (solid line) and N.W. Branch Anacostia River (dashed line), Maryland.

Figure 4. Sedihydrograms for Rio Puerco (upper left) and Gila River (lower right), New Mexico

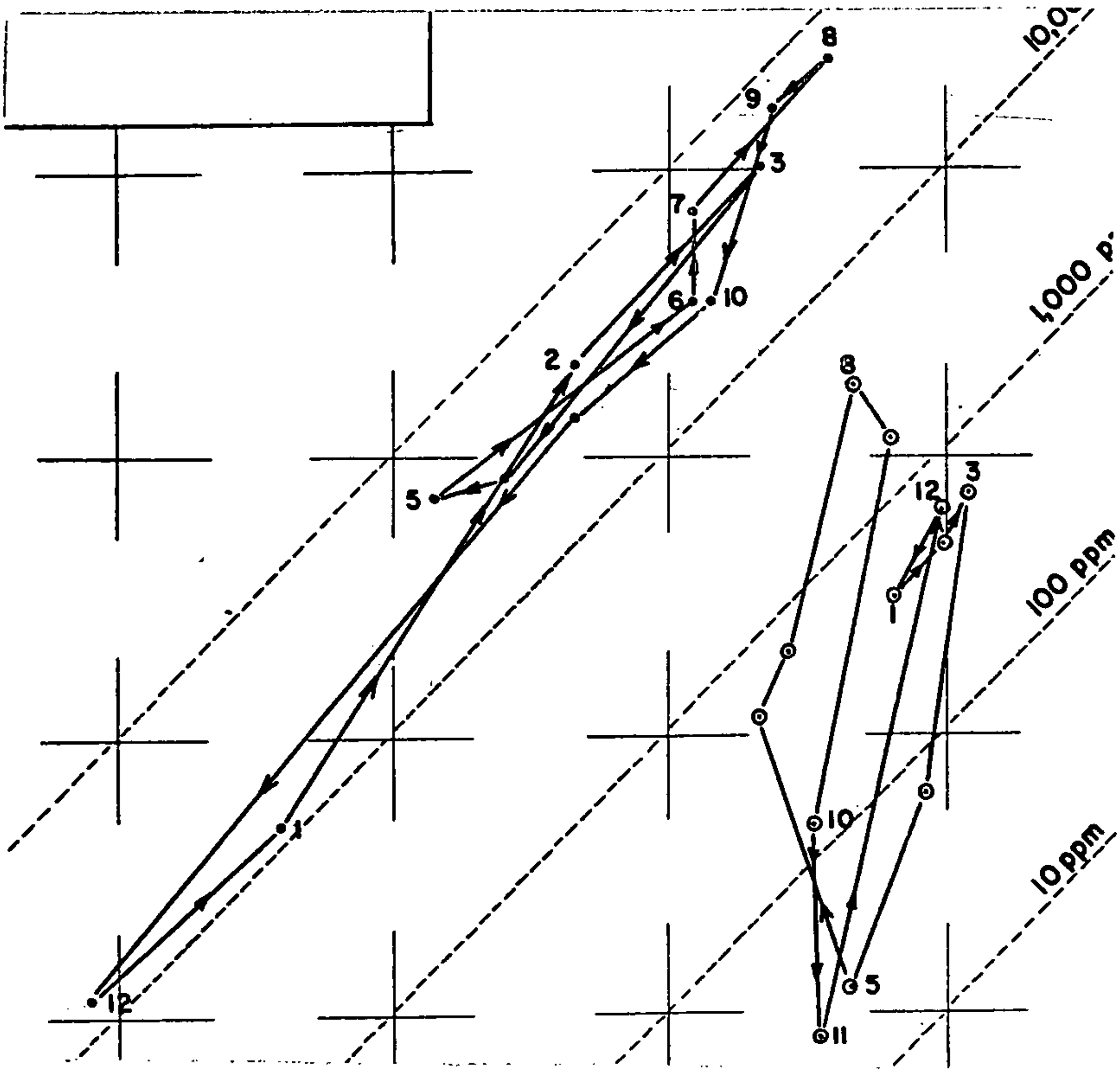


Figure 6. Mean annual sediment yield as a function of mean annual precipitation. Solid line from Langbein and Schumm, 1958, who used about 265 basins from the U.S.; dashed line based on work of Wilson (e.g. 1969 & this paper), using 1500 basins from much of the world.

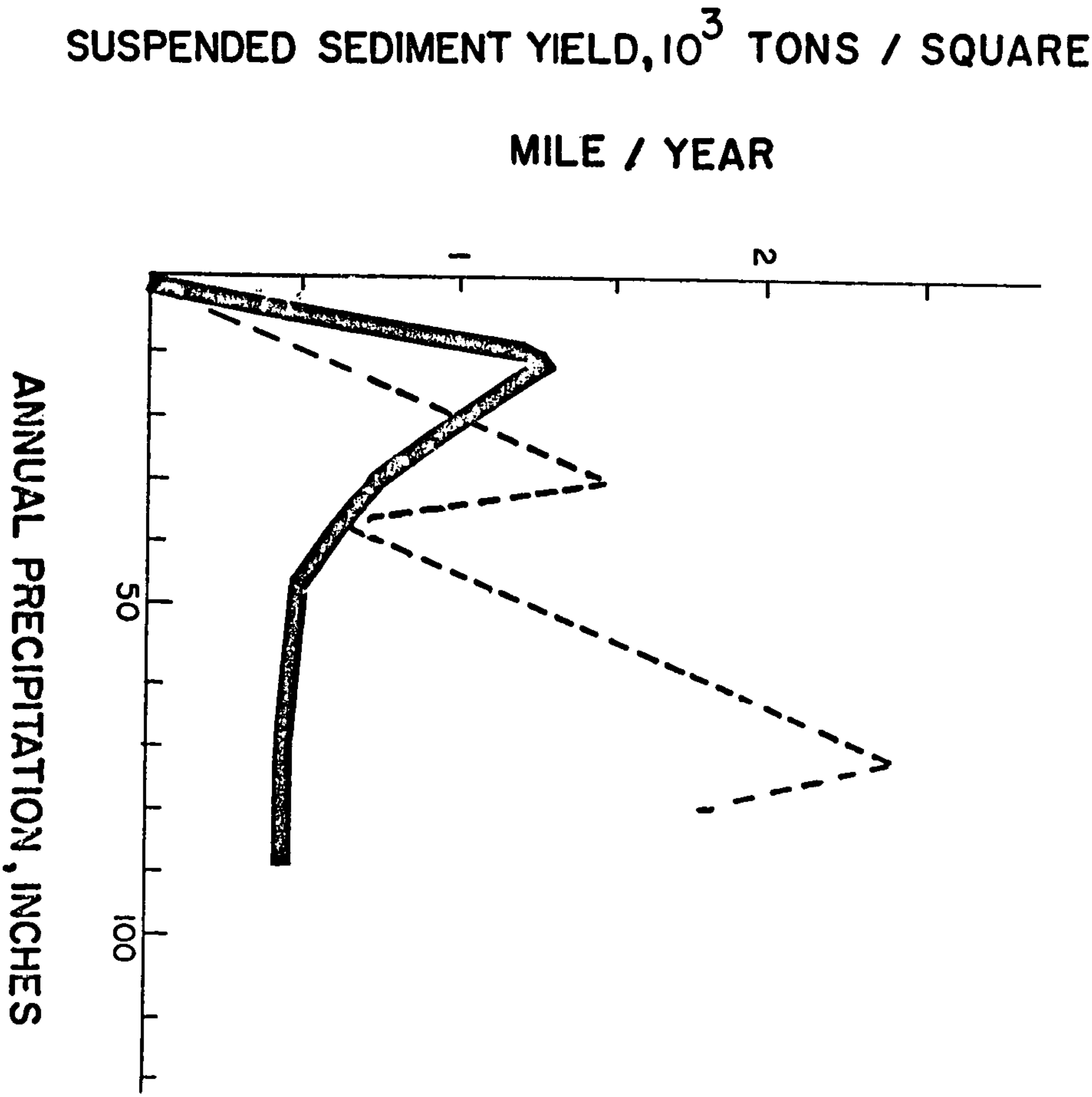
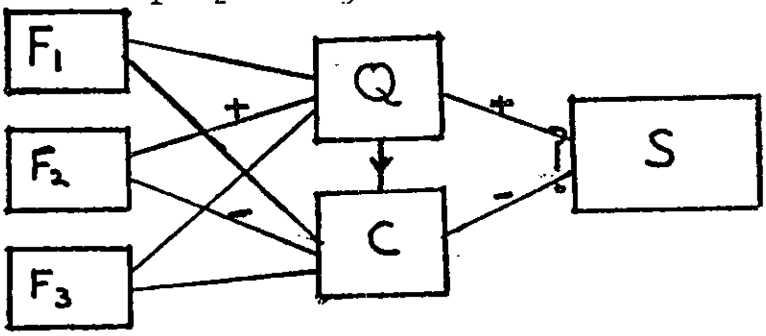


Figure 7. Simple model showing that sediment yield (S) is a function of water yield or runoff (Q) and sediment concentration (C). These flow variables in turn vary in response to various environmental factors, such as F_1, F_2, and F_3.



F_2 is mean annual precipitation in this particular example. An increase of F_2 results in increased Q, decreased C, and a complex relationship with S. This relationship is seen in figure 1a, for basins with a Continental climate.

A STATISTICALLY BASED MATHEMATICAL WATER QUALITY MODEL FOR A NON-ESTUARINE RIVER SYSTEM (UPPER PASSAIC VALLEY IN NEW JERSEY)

by

MICHAEL A. TIRABASSI, Ph.D.

Assistant Professor of Management Science, Stevens Institute of Technology, Hoboken, New Jersey

Introduction

Intent

There are primarily two ways of developing a model for the purpose of forecasting river water quality. One is the construction of a theoretical model which is based on the structure of the causal chemical, biological, and physical relationships of water quality parameters. The second develops the mathematical dependence among water quality parameters on a purely statistical basis. Owing to the highly complex nature of the causal interactive systems, construction of the former type of model has proven to be an enormous task. Consequently, this type of predictive model exists for a very few water quality indicators, such as dissolved oxygen and biological oxygen demand. Even so, mathematical constants, such as reaction rates, which are necessary for numerical evaluation of these model equations, require a considerable amount of data reduction and analysis.

This study concerns itself with the formulation of these water quality relationships from a mathematical statistics viewpoint and will demonstrate that, with a sufficient amount of water quality data available, this methodology will enable the analyst to produce satisfactorily accurate results (i.e., order of magnitude ± 3 percent) in the predicted value of water quality parameters with a minimum of time and effort expended. Further, this will be accomplished without dealing with the complexities of these causal relationships. It should be noted that statistical dependence among water quality parameters does not necessarily imply causal dependence. Consequently, statistical relationships among water quality parameters may be used in their mutual prediction without assumptions of causal dependence.

This methodology is applicable to any water quality (for which sufficient data is available) indicator in any non-estuarine river system. This paper describes an application of this technique in the Passaic River Basin, specifically in the Upper Passaic Watershed. Relationships among certain water quality parameters of interest were developed and verified for six sampling sites along the Passaic River, utilizing the above methods.

As part of a study (funded by the Office of Water Resources Research, Department of the Interior) investigating the industrial growth potential of the Upper Passaic Watershed (fig. 1), our attention was drawn to the Passaic River as one of the most critical constraints to be considered in the development of this river basin. The Passaic is an old, slow-flowing river with consequent low recovery patterns. Many firms that settled along the Passaic did so because they expected to use the river to carry away their waste. In addition, approximately 117 sewage treatment plants, which are small, outmoded, and often operate above capacity, add to an already bad situation. During critical low flow periods in summer months it is not uncommon to have an effluent to river ratio of 1.

This creates an especially serious problem since the Passaic is also used as a source of potable water by the Passaic Valley Water Commission, which withdraws approximately 75 million gallons daily at its Little Falls intake (fig. 1). Their water purification plant at Little Falls has often been referred to as a sewage treatment facility because of the critically poor quality of the Passaic.

Accordingly, in order to fully evaluate the impact of future development in the basin, it became necessary to first evaluate the impact of this potential development on the Passaic River itself. Thus we sought a model that would represent the effect of changing effluent loading patterns on the Passaic in terms of water quality parameters reflective of water quality in this basin. Clearly, these crucial parameters must be drawn from an examination of the user profile of the basin. Arising out of this study were parameters such as nitrates, ammonia, carbon dioxide, chlorides, and pH, as well as dissolved oxygen and biological oxygen demand, the latter two of which are of more common interest. Since causal relationships relating the above parameters, one to the other, simply do not exist, we embarked on an effort to represent these relationships through statistical approximations, within a specified degree of accuracy.

Data Acquisition

The study area includes the Passaic River above its confluence with the Pompton which drains an area of approximately 160 square miles (fig. 1). The Passaic Valley Water Commission has supplied in-stream sampling data on 17 different water quality parameters for 7 sampling sites (fig. 2; tables 1 and 2) along the Upper Passaic River. This data is taken on a biweekly basis with the exception of sample sites numbered 100 and 110, which are taken daily. Data taken over a period of approximately five years, 1963 to 1968, was utilized. The above data was taken largely during base flow conditions, and corresponding river flow data over the same period of time was obtained from the U.S. Geological Survey for data locations as indicated above. Where flow gages did not exist at sample sites, extrapolations of records at flow gaging stations were made based on regression curves of flow gaging stations versus partial records gaging stations. These regression curves were developed by the U.S. Geological Survey and are calibrated on a periodic basis.

In order to develop an insight into the dynamics of the river, and develop distributions of the temporal response of critical water quality parameters, it was necessary to install an electronic, continuous monitoring device on the Passaic. Factors considered in selection of the site for this device were: (1) location of other data stations; (2) effluent loading characteristics of the river; (3) hydrologic characteristics of the river, which includes confluence of the Passaic with any other river(s) that may affect water quality; and (4) accessibility. The site chosen was a small precipice at the confluence of the Pompton and Passaic Rivers (figs. 3 and 4). This site had several advantages: (1) the Pompton River has an ameliorating effect on the Passaic (dilution); (2) both the Passaic and Pompton Rivers may be monitored with one device; and (3) with a second D.O. analyzer downstream at Station 100, we would have continuous monitoring of this critical parameter at two comparatively near sites. This device provided data on dissolved oxygen, pH, temperature, turbidity, conductivity, oxidation reduction potential, solar radiation, and chlorides. The device received water alternately from two submersible pumps, one in each river, on 30-minute switchover cycles. The information was recorded on pen strip charts which were calibrated so as to make recordings from each river easily discernible.

Statistical Analysis

Before proceeding into the detailed statistical analysis of the model equation, the author feels a relation of an overview of the functional use of the model will be beneficial to the reader's understanding. The statistical water quality model herein discussed deals with two basically different types of relationships. The first represents the relationship among a number of water quality parameters at a given data station or sampling site (fig. 2). These will hereafter be referred to as "within station relationships." The second relates the upstream and downstream values of a particular water quality parameter. These will hereafter be referred to as "inter-station relationships." A model containing both types of these relationships would function operationally as follows: (1) a change in known effluent loading conditions on the river would be the initial stimulus to the model; (2) through volumetric flow mixing equations, changes in values of those water quality parameters directly affected by these effluent loads would be computed; (3) resulting changes in all other water quality parameters would be computed for that location through use of the "within station relationships"; and (4) the effect of this changing effluent load is propagated downstream by use of the "inter-station relationships."

With reference to point (1) above, a detailed analysis of the effluent profile of a number of Standard Industrial Code (United States Standard Industrial Classification) industry categories common to the Passaic Basin was made. This study is beyond the scope of this paper, however, for further information refer to Lesser and others (1970). A computer simulation program has been designed for the purpose of obtaining a solution to the statistical model equations, which are the subject of this paper. Briefly, this simulation program (Lesser and others, 1970) would compute the values of all water quality parameters at each data station at time intervals of Δt (t being a period of time which is system dependent), and print these values as output. These results may be plotted to show the variability of each water quality parameter at each data station (fig. 5). System flow logic for this computer simulation program is given in figure 6. Table 3 shows the format of hypothetical output of the program for Δt of .1 hour and a hypothetical effluent loading pattern called No. 605. The reader should note that a change in the effluent loading pattern will result in changes in the moments of the distributions shown (variability, median, skewness, kurtosis), which in turn reflect resulting changes on the river water quality parameters as effluent loading patterns change.

The statistical model

As occurs with the use of most empirical data, some necessary data points were missing. These points were satisfactorily handled by the use of Hicks' (1964) method of incomplete block design. Simply speaking, these points are constructed so as to minimize the sum of squares of the error terms associated with the analysis of variance. Generally it has been found that use of this method has little effect on the validity of the resulting statistical model.

The functional characteristics of a model must be consistent with the nature of the variables involved. Accordingly, scatter diagrams of the data were constructed to derive a general picture of the behavior of the data. Examination of these diagrams led to the intuitive decision to select an intrinsically linear model both for inter and within station relationships. That is, the function relating the means of the conditional distribution with the independent variable is linear, or the function may be of such a nature that it is linear in terms of transformed variables. For example, consider the regression curve of Y on X; if this regression is linear the mean of the distribution of the Y's is given by:

$$(1) \quad Y = \alpha + \beta X$$

If, however, a set of paired data consisting of n points (X_i, Y_i) "straightens out" when plotted on semi-log paper, this implies the regression curve of Y on X is exponential; namely, that for any given X, the mean of the distribution of Y's is given by $\alpha\beta^x$.

$$(2) \quad Y = \alpha\beta^x$$

Taking logarithms of both sides of equation (2) we have:

$$(3) \quad \log Y = \log \alpha + X \log \beta$$

Seeking estimates of $\log \alpha$ and $\log \beta$ we may now consider n pairs of values $(X_i, \log Y_i)$ and proceed with a "least squares" fitting of the exponential curve in exactly the same manner as for equation (1) above. Equation (3) then, represents an "intrinsically" linear relationship. As the reader will see, almost all within and inter-station model equations did in fact result in either linear or intrinsically linear (though not all exponential) relationships. Further, the model equations were found to be linearly statistically significant for the purpose of predictability.

In addition to the above, the scatter charts served one further useful purpose, and that is verification of internal consistency of the data. Imposition of upper and lower statistical control limits (Grant, 1964), computed from the mean and range of the raw data, provided information on whether this data was in statistical control. For example, an out-of-control water quality reading might result from the river being in non-base flow configuration when the sample was taken. Since the statistical dependence of one water quality parameter on another may conceivably change along with changing environmental conditions, this reading would bias the resulting model equations. Therefore, an effort was made to determine the causes of all out-of-control data, and adjustments were made accordingly.

It would also seem reasonable to suspect that seasonal effects might vary the functional relationships sought. Further, exactly how the year should be divided (the Passaic Basin being in the Northern Temperate Zone has four seasons), quadriannually, triannually, biannually, etc., is another problem. These seasonal effects were handled in two ways: (1) the raw data was analyzed for significant differences in the central tendencies of the various seasonal groupings; and (2) the statistical model equations were derived separately for the different seasonal periods. With the resulting equations being tested through Analysis of Variance Techniques. Part (2) above will be described in greater detail later in the paper. Part (1) was accomplished by subdividing the data as follows:

Annual	Months 1 through 12
Biannual	Months 6-11 and 12-5
Triannual	Months 1-4, 5-8, and 9-12
Quadriannual	Months 1-3, 4-6, 7-9, and 10-12

Taking all possible pairwise combinations--annual with biannual, triannual with biannual, etc., for all 17 water quality parameters plus flow at all data stations--the means of these distributions were checked for statistically significant differences. (For sample results see table 4.) The method used is as follows:

N_{A1} = number of data points for annual breakdown of parameter 1

N_{B1} = number of data points for biannual breakdown of parameter 1

$\overline{X}_{A1}$ = mean of data; parameter A1

$\overline{X}_{B1}$ = mean of data; parameter B1

S_{A1} = sample standard deviation; parameter 1 annual

S_{B1} = sample standard deviation; parameter 1 biannual

α = probability of error in judging result significantly different if not significantly different

The sampling distribution used to check the significance of difference in the means of the population of water quality parameters can be shown to be a t distribution with $(N_{A1} + N_{B1} - 2)$ degrees of freedom:

$$(4) \quad t_\alpha = \frac{(\bar{X}_{A1} - \bar{X}_{B1})}{\sqrt{(N_{A1} - 1)\, S^2_{A1} + (N_{B1} - 1)\, S^2_{B1}}} \sqrt{\frac{N_{A1}\, N_{B1}\, (N_{A1} + N_{B1} - 2)}{N_{A1} + N_{B1}}}$$

This analysis was carried through as described above with the results showing that (see fig. 5) most water quality parameters have significantly different raw data distributions from season to season in all yearly breakdowns. This would seem to imply that the functional relationship to be developed among water quality parameters would also vary significantly from season to season. This is later shown to be true.

Within station relationships

Prior to developing relationships including all water quality parameters plus flow, pairwise correlation coefficients were developed for all stations. This pairwise analysis revealed two necessary pieces of information: (1) sensitivity and statistical dependence was revealed on a partial effect basis; and (2) the dynamics or change in the relationship between variables at different locations on the river became apparent. At this point it would be a simple matter to construct a multiple regression model with each of the 18 water quality parameters taken sequentially as an independent variable, with those water quality parameters having the highest pairwise correlation as dependent variables in each case. However, we not only wish reliable predictive capabilities but we also recognize that minimization of time, money, and effort in water quality surveillance equipment and techniques can be accomplished only by a reduction in both frequency of measurement and number of water quality parameters needed to maintain and assure meeting approved water quality standards. In terms of the statistical model we seek:

$$X = f\,(Y_A, Y_B, Y_C, \ldots, Y_n)$$

We wish to predict X as accurately as possible with the fewest number of independent variables Y. In statistical terminology then, the following questions arise:

(1) What portion of the explained variation of the dependent variable is contributed by each independent variable; is it statistically significant?

(2) How does the removal of one or several nonsignificant independent variables affect those remaining in the functional relationship?

Satisfaction of the questions asked above implies a "least form equation" that will be a truly significant linear or intrinsically linear relationship containing only those variables that significantly contribute to the explained variation of the dependent variable. To satisfy the above constraints, a variation of the Gaussian elimination method (Ralston and Wolf, 1967) was utilized in the design of a stepwise intrinsically linear multiple correlation analysis. This author refers the interested reader to either Ralston and Wolf (1967) or the author's Ph.D. thesis for the theoretical mathematics and derivation of this approach, which are beyond the scope of this paper. A computer program was written to perform the required computations, which is capable of handling 10,000 observations of up to 100 water quality variables each run. The actual analysis performed is as follows:

(1) All data points for all water quality parameters at all sites are read in, and a matrix of sums of squares, cross products, and partial correlation coefficients is computed for all variables.

(2) The coefficients of the multiple linear regression equation, which shows dependence of one variable as function of the remaining independent variables, are computed. These regression coefficients are computed by forming a sequence of regression equations, each containing one more independent variable than the previous one. At each "step" the program either removes from the equation a variable whose contribution to the estimator of the dependent variable is insignificant as measured by the "removal" F-level (Sum of Squares Regression/Sum of Squares Error), or, if no variable can be removed, the variable which produces the largest reduction in the unexplained variance of the dependent variable; provided that this reduction is significant as measured by the entry F-level.

(3) Redundancies in each equation are also minimal since, if the multiple correlation coefficient between a number of so-called independent variables is so large that most of the variability of one independent variable is related to the other independent variables, this variable will not be placed in regression.

The above analysis was completed for all sites referenced in this paper and done for annual, biannual, and triannual groups of seasonal data. The resulting equations, grouped seasonally, were found to be all mutually significantly different, statistically speaking. (Sum of Squares Regression_2 - Sum of Squares Regression_1/Sum of Squares Error.) The author chose a biannual grouping of data for the final model due to: (1) the advantage of a larger number of data points (higher statistical confidence) per time period; and (2) the natural "warm-cold" months seasonal difference. Table 5 shows resulting model equations for the period June through November for Station 100 on the Passaic River.

Verification of the above model has been accomplished through a "backfitting" approach. In other words, the model equations have been used to forecast the past. The results have been excellent in that predictive capabilities have yielded no greater than 3 percent error. Figure 7 shows the actual values of concentration of chlorine (ppm) plotted on the same axis as the values predicted via the appropriate model equations. The high degree of correlation of one with the other is apparent. While most of the 18 water quality predicting equations have been verified as reliable within the above mentioned bounds, a few have deviated more than this guideline. In most cases the researcher has traced these apparent inconsistencies either to missing data, which had been replaced with some incomplete block design, or to data taken during nonbase flow conditions which had been inadvertently used as input to the model computations.

Inter-station relationships

Knowledge of variation of water quality parameters from upstream to downstream on the Passaic led the researcher to an intuitive belief that these variations would be linear or intrinsically linear. Consequently, an attempt to generate such relationships was done initially through graphical analysis. Plots were made of each variable versus itself for all combinations of sites on the Passaic. Not surprisingly, these results substantiated the expectation of linear relationships. Only 19 out of 108 equations derived from fitted curves necessitated a logarithmic-exponential fit. Notably, those parameters most often nonlinear were turbidity, odor, nitrites, and coliform. In addition, the least squares regression technique was fitted to these data for verification of the graphical results. These results did substantiate the graphical analysis (partial results are shown in table 6).

Conclusion

Clearly, the advantage of the described methods in forecasting and computing values of river water quality parameters is the construction of these models without reference to the causal chemical, biological, and physical relationships. Not only is reference to these relationships unnecessary, but since it is entirely possible for statistical dependence to exist without causal dependence, it becomes possible to predict water quality values solely as a function of non-physically related parameters. In a sense, this is a "black box" approach wherein with a known input, one may reliably predict the output. Very often, in water quality systems and analysis it is of primary importance to develop relationships capable of accurately predicting system performance under varying environmental conditions in order to critically analyze alternative configurations of the system. In this instance these modeling equations permitted evaluation of river water quality under varying hypothetical effluent loading configurations. In other instances it may be necessary to predict the impact on the river of upgrading certain waste treatment facilities or stricter enforcement of certain water quality standards. Whatever the case, the mathematical statistics can provide a sound basis for reliable, accurate, water quality modeling at a great saving in time, effort, and expense.

References Cited

American Public Health Association, American Water Works Association, Water Pollution Control Federation, 1967, Standard methods for the examination of water and wastewater: New York, Am. Public Health Association.

Besselievre, Edmund B., 1952, Industrial waste treatment: New York, McGraw-Hill, 391 p.

Bower, B. T., Gordon, P. E., Larson, P., Michaels, A., and Phillips, W. M., 1968, Waste management: New York, Regional Plan Association.

Cox, J. Grady, and Mize, Joseph H., 1968, Essentials of simulation: New Jersey, Prentice-Hall.

Goldberger, Arthur S., 1968, Topics in regression analysis: New York, MacMillan Co.

Grant, E. L., 1964, Statistical quality control: New York, McGraw-Hill.

Gurnham, C. F., ed., 1965, Industrial wastewater control: New York, Academic Press, 476 p.

Hicks, C. R., 1964, Fundamental concepts in the design of experiments: New York, Holt, Rinehart and Winston.

Killam, E. T., Associates, 1967, Pollution abatement study for watersheds of Morris County, pts. 1 and 2: New Jersey.

Killam, E. T., Associates, 1969, Water and sewerage study, 1st phase: New Jersey.

Lesser, A., Spinner, A., Tirabassi, M., 1970, An engineering economic study of the industrial growth potential of the Upper Passaic River Basins: Office of Water Resources Research.

Morris County, New Jersey, 1967, Morris County industrial directory.

New Jersey State, 1967, New Jersey State industrial directory: New York.

Ralston, A., Wolf, H. S., 1967, Mathematical methods for digital computers, v. I and II: New York, John Wiley and Sons.

Rice, C. W., and Company, The cost of clean water and its economic impact, v. IV: U.S. Dept. of the Interior, Federal Water Pollution Control Admin.

Rudolfs, W., ed., Industrial wastes, their disposal and treatment: New York, L.E.C. Publishers, Inc.

U.S. Dept. of the Interior, Federal Water Pollution Control Administration, 1969, The cost of clean water and its economic impact, v. 1, 2, and 3.

U.S. Dept. of the Interior, Federal Water Pollution Control Administration, 1969, The cost of clean water: Industrial Waste Profile, nos. 1-10.

Table 1

Description Of Sampling Sites

Station Number	Location	Latitude	Longitude	Miles Above Intake	Description*
100	Little Falls	40° 53'	74° 14'	0	a, b
110	Two Bridges	40° 53'	74° 16'	3.2	a, c
120	Pine Brook Bridge	40° 51'	74° 19'	13.4	a, c
130	Swinefield Bridge	40° 49'	74° 20'	16.6	a
140	Cook's Bridge	40° 47'	74° 21'	19.2	a, c
165	Main Street, Chatham	40° 43'	74° 22'	25.8	a, b
180	Basking Ridge	40° 42'	74° 31'	42.1	a, c

*a - Passaic Valley Water Commission Water Quality Monitoring Site

b - United States Geological Survey Flow Gaging Station

c - United States Geological Survey Partial Records Flow Gaging Station

Survey of Streams within the Passaic Valley Watershed drainage area: By The U.S. Geological Survey, Division of Water Resources, The New Jersey State Department Of Health and Passaic Valley Water Commission.

Sixteenth Set — JANUARY 19 Th. 1965 — By Frank J. De Hooge

STATION / LOCATION / TIME	LAB. REG. NO.	HARDNESS	TEMP	TURB	COLOR	PH	ALK	FREE CO_2	ODOR	CHLORIDE	OXYGEN D.O. PPM	OXYGEN % Sat.	OXYGEN 5 Day P.P.M.	NITROGEN AS Nitrite	NITROGEN AS Nitrate	NITROGEN AS Ammonia	BACTERIOLOGICAL Total Plate Count on Agar @ 35.5° C	BACTERIOLOGICAL Coliform Organism's M.P.N. Per 100/cc
(100) Passaic at L.F. Intake 9.00 AM	8656	133.	34	11	35	6.9	66	13	5 MMm	36.0	9.0	63	7.7	.050	.850	2.0	1,600	390
(110) Passaic At Two Bdgs. 11.00 AM	8658	110.	33	10	45	6.9	90	18	8MMm	49.0	6.8	47	11.7	.040	.610	3.2	7,600	240
(120) Passaic At Bloomfield Ave8.40 AM	8659	134.	33	52	62	7.0	100	18	2MMm	57.0	7.0	49	31.0	.045	.520	3.4	15,000	700
(140) Passaic At Rt. 10,Bdg. 9.20 AM	8661	112	32	8	34	6.9	62	12	160s	61.0	9.9	68	4.8	.008	.500	2.2	170	700
(165) Passaic At Stanley Ave. 11.00 AM	8662	106.	32	11	37	6.8	52	14	120s	45.0	9.1	63	6.6	.010	.600	1.2	180	240
(180) Passaic At Basking Rdg. 11.55 AM	8663	100.	33	3	35	6.0	24	24	3 MV	19.0	6.0	42	1.6	.005	.330	0.12	390	700
(210) Whippany At Edwards Road, 8.55 AM	8664	138.	38	165	155	7.0	114	18	Paper 240	37.0	5.6	42	82.0	.055	.210	2.2	65,000	620
(230) Whippany At Rt. 10.Bdg. 9.45 AM	8665	136.	48	250	260	6.9	112	20	Paper 400	47.0	6.1	53	120.	.060	.210	4.3	33,000	620
(260) Whippany at Eden Lane(Dam)1030 AM	8667	100.	34	7	26	7.2	74	8	6 Ds	20.0	12.0	85	5.6	.040	.720	1.4	40	240
(280) Whippany At Hanover Ave. 1050 AM	8668	93.	33	4	22	7.4	60	6	3 MV	17.0	13.5	94	4.6	.048	1.40	0.42	770	2,400
(310) Rockaway At Rt. 46,Bdg. 8.30 AM	8669	138.	33	12	37	7.2	138	18	200s	36.0	7.6	53	19.0	.035	1.00	8.0	80	23
(350) Rockaway At Morris Ave. 8.45 AM	8670	72.	33	2	17	7.5	42	4	3 MV	10.0	14.3	100	4.1	.001	.200	0.06	80	240
(610) Pompton At Two Bdgs. 11.10 AM	8673	86.	33	3	17	7.0	42	8	3 MV	17.0	12.8	89	3.9	.007	.510	0.36	440	700
(650) Pompton At Jackson Ave. 10.30 AM	8674	84.	34	2	12	7.0	42	8	4 Ds	15.0	12.8	90	3.4	.007	.100	0.50	100	700

REMARKS: Total River Flow at Little Falls, when samples were taken was 145 C.F.S. = to 94.0M.G. (A.D.)

Sample Data Taken By Passaic Valley Water Commission

TABLE 2

TABLE 3

Run #800
Length 1000 X .1 Hr.
Effluent Load Pattern #605

Hypothetical Output Of Simulation Model

Ph Value	0-<.5...	3.0-<3.5...	5.5-<6.0	6.0-<6.5	6.5-<7.0	7.0-<7.5	7.5-<8.0...	9.5-<10.0
Station 100	0	0	15	227	491	216	13	0
Station 110	0	1	12	212	460	270	18	0
Station 120	0	0	16	214	471	253	20	0
Station 130	0	0	14	238	486	215	11	0
Station 140	0	0	21	219	509	204	22	0
Station 165	0	0	21	235	479	220	16	0
Station 180	0	1	20	208	514	232	12	0

D.O. Value (PPM)	1-<2...	4-<5	5-<6	6-<7	7-<8	8-<9	9-<10	10-<11	11-<12	12-<13...	19-<20
Station 100	0	9	28	73	182	510	91	44	31	11	0
Station 110	1	10	32	71	173	536	85	40	38	9	0
Station 120	1	14	35	54	158	572	88	49	28	7	0
Station 130	2	11	36	59	120	583	95	52	34	10	0
Station 140	0	10	27	42	104	618	98	48	30	14	0
Station 165	0	6	29	48	100	604	107	51	27	15	0
Station 180	1	13	34	51	103	596	112	46	31	17	0

TABLE 4

Summary Of Seasonally Significant Water Quality Parameters
(Annual vs. Biannual Tests)+

Independent Variable	Sites						
	100	110	120	130	140	165	180
1. Temp.	* *	* *	* *	* *	* *	* *	* *
2. Turb.					*		
3. Color	* *	*	* *	*			* *
4. Odor					*		
5. Hard.							
6. Alk.					* *	* *	* *
7. pH	* *						
8. CO_2							
9. Chl.							* *
10. D.O.	* *	* *	* *	* *	* *	* *	* *
11. Sat.			* *		* *	* *	
12. BOD							
13. NO_2	*				*		
14. NO_3	* *						
15. NH_3					*	* *	
16. Plate Count	* *	*	* *	*		*	
17. Coli.							
18. Flow	* *	* *	* *	* *	* *	* *	* *

Significant at:

* Alpha = .05

* * Alpha = .01

Blanks indicate non-significance

+See Appendix iv for statistical method

TABLE 5

Station 100
June through November

Sample - Least Form Correlation Relationships

Dependent Variable		Least Form Equations
1.	Temp.	$= - .192Y_5 + 33.368Y_7 - 1.092Y_{12} - 2.584Y_{13} - 1.293Y_{15} - .128Y_{17} - 140.023$
2.	Turb.	$= - .515Y_1 + .500Y_3 + .314Y_5 - .500Y_6 - 2.505Y_8 + .623Y_9 - .228Y_{11} + .457Y_{17} + 39.183$
3.	Color	$= + .640Y_1 + .961Y_2 + 2.819Y_8 - .566Y_9 + .604Y_{11} - .282Y_{17} - 31.909$
4.	Odor	$= + .209Y_{15} + 5.668$
5.	Hard.	$= - .443Y_1 + .261Y_2 + .522Y_6 - .481Y_{17} + 88.681$
6.	Alk.	$= + .260Y_5 + 54.121Y_7 + 1.049Y_8 + .573Y_9 - .197Y_{11} + .120Y_{16} - 357.371$
7.	pH	$= - .040Y_4 - .003Y_5 + .008Y_6 - .027Y_8 + .004Y_9 - .009Y_{10} + .002Y_{11} - .019Y_{14} - .001Y_{16} + .001Y_{17} + 7.173$
8.	CO_2	$= -.089Y_2 + .037Y_3 - .679Y_4 - 10.670Y_7 + .135Y_9 - .068Y_{11} + .290Y_{12} - .022Y_{16} + .648Y_{17} + 88.573$
9.	Chl.	$= + .422Y_6 - .682$
10.	D.O.	$= + .001Y_{18} + 5.648$
11.	Sat.	$= + .475Y_3 - .270Y_5 - .246Y_6 - 3.262Y_8 + 1.616Y_{12} + 3.052Y_{13} - .030Y_{18} + 104.810$
12.	BOD	$= - .143Y_1 + .089Y_6 + .070Y_{11} - .679Y_{13} + 4.82$
13.	NO_2	$= - .131Y_4 + .961Y_7 + .965Y_{14} - 6.264$
14.	NO_3	$= + .125Y_4 - .989Y_7 + .966Y_{13} + 6.546$
15.	NH_3	$= + .788Y_4 + .041Y_6 - 5.932$
16.	PC	$= - .173Y_3 + .735Y_6 - 69.524Y_7 - 3.515Y_8 - 7.390Y_{14} + 2.424Y_{15} + 536.472$
17.	Coli.	$= + .816Y_2 - 1.007Y_5 + 1.456Y_8 - .029Y_{18} + 92.993$
18.	Flow	$= + 1558.156Y_{10} - 5663.109$

Y_i is the value of variable number i $(1 \le i \le 18)$ when appearing as an independent variable on the right half of the equation.

TABLE 6

Graphical Linear Regression Equations For Inter-Station Relationships Among Water Quality Parameters

Parameter	Station 180 vs. Station 165*	Station 165 vs. Station 140*	Station 140 vs. Station 130*
Temperature	Y = 1.0145X	Y = 1.0145X	Y = X
Turbidity	Y = 2.6923X	* Y = 1.3725X	Y = .9456X + 1.0
Color	Y = .6575X + 21.	Y = .8816X + 6.0	Y = .7356X + 12.0
Odor	Y = 10.3704X - 4	* Y = .0208X + 7.95	Y = .1025X + 9.0
Hardness	Y = 1.6429X - 21	Y = 1.0960X + 3.0	Y = 1.0147X + 2.0
Alkalinity	Y = 1.5955X - 2.	Y = 1.0271X + 7.5	Y = 1.0642X - 1.0
pH	Y = .8077X + 1.7	Y = .7595X + 1.68	Y = .9247X + 0.512
CO_2	Y = .4425X + 2.8	Y = .9962X + 2.1	Y = 1.1966X
Chlorides	Y = 56X - 540	Y = .7620X + 12.5	Y = .9719X + 1.5
D.O.	Y = 1.1200X + 0.	Y = 1.0526X - 1.263	Y = .9133X + 0.3
% Saturation	Y = 1.1523X	Y = X - 8.5	Y = 1.0487X - 5.24
B.O.D.	* Y = 3.7838X - 2.	Y = 1.2500X - 0.45	Y = 1.1458X + 0.25
NO_2	Y = 40.6250X + C	Y = .8313X + 0.002	* Y = .8986X + 0.007
NO_3	Y = 1.5419X + 0.	Y = X	Y = 1.0145X
NH_3	* Y = 31.1111X - [illegible]	Y = 2.0588X	Y = .8233X + 0.33
Plate Count	* Y = 14X - 28	Y = .8667X + 5.0	* Y = .7809X + 0.5
Coliform	* Y = 2.3729X	* Y = 1.0256X + 2.0	* Y = .9150X
Flow	Y = 12.7273X	Y = 1.2613X	Y = X

* Equation as replaced by intrinsically linear function.

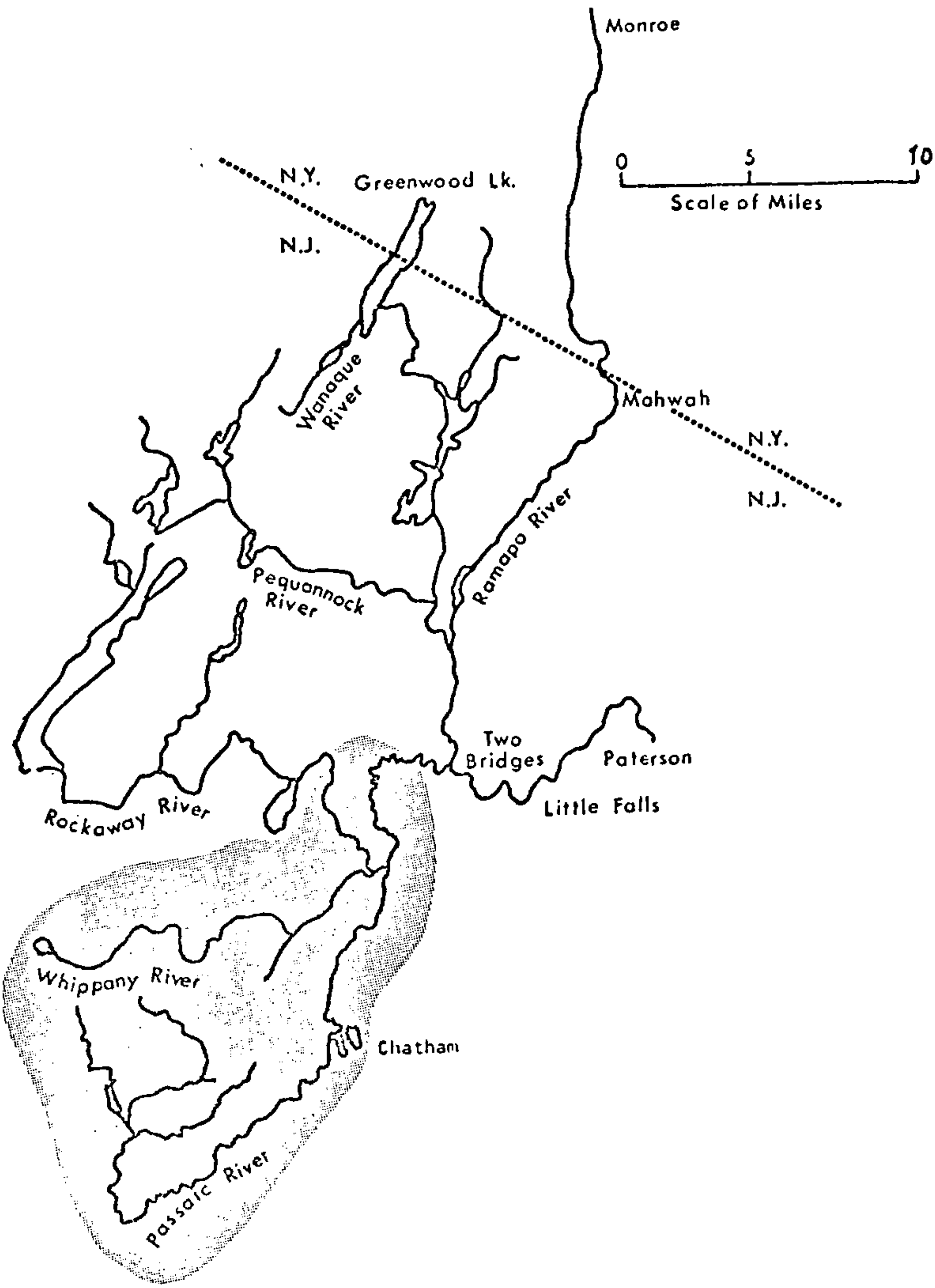


FIG. I UPPER PASSAIC WATERSHED

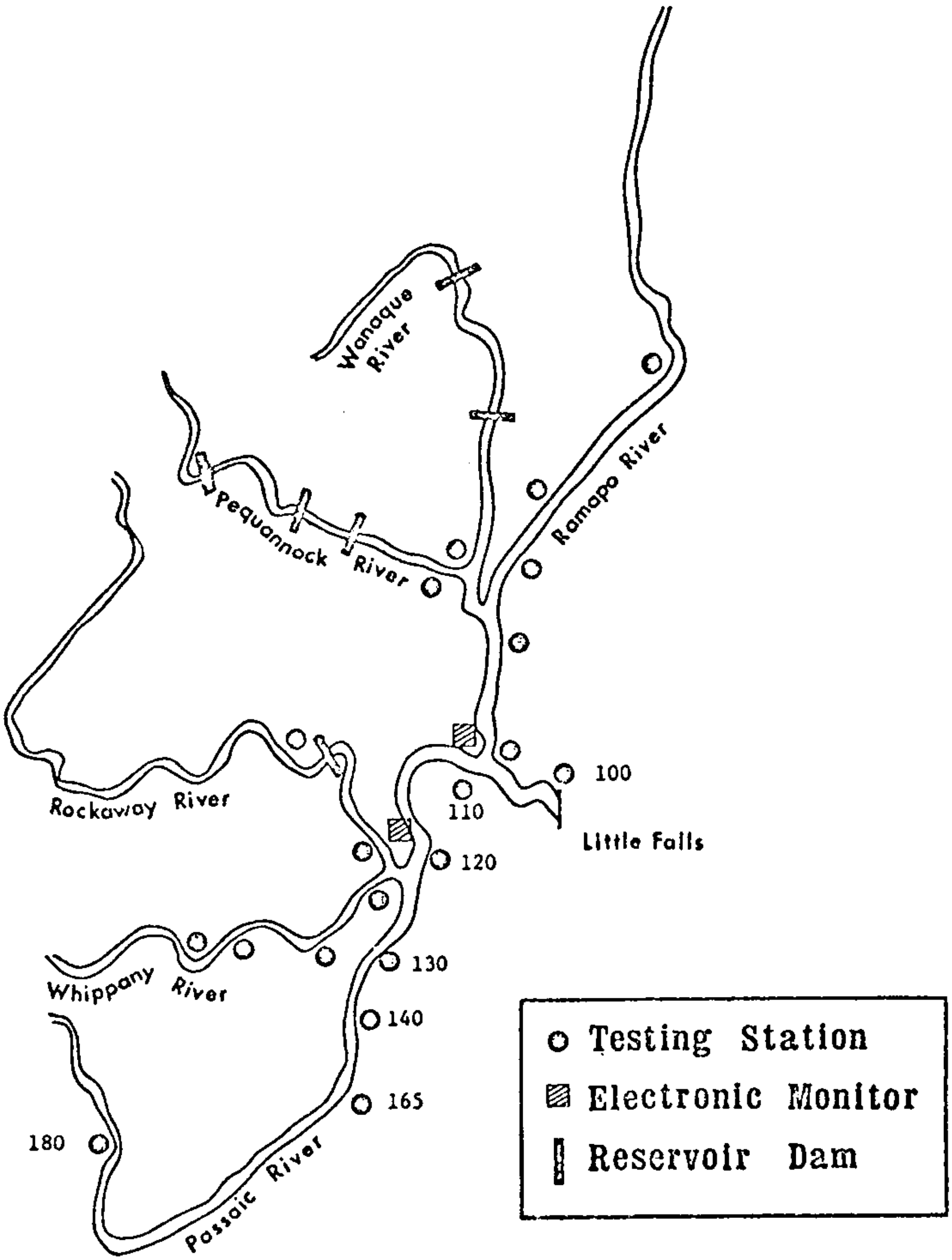


FIG. 2 SAMPLING SITES ON THE PASSAIC WATERSHED.

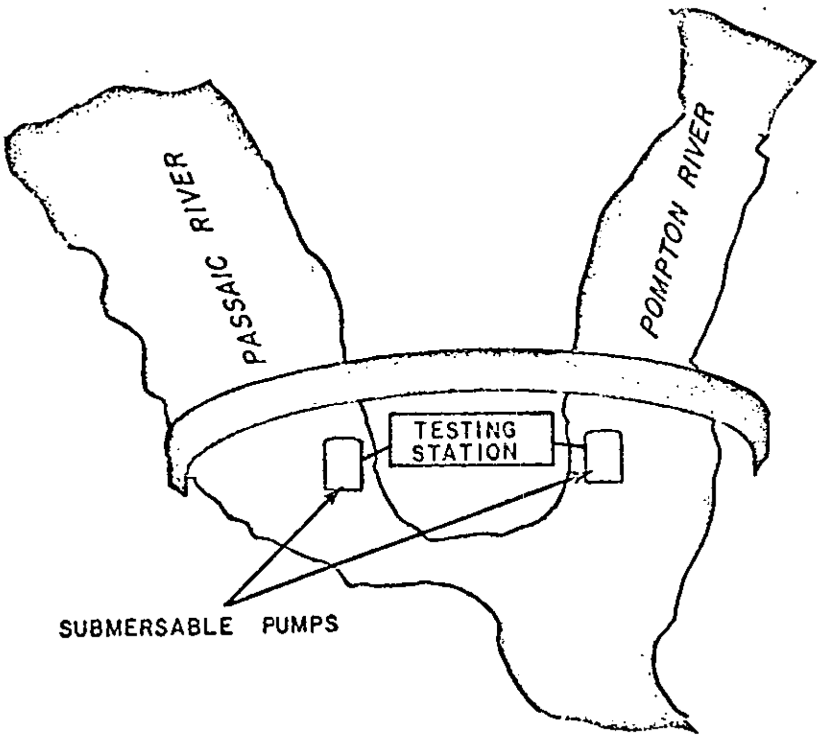


FIG. 3 LAYOUT OF BECKMAN ELECTRONIC MONITORING DEVISE AT TWO BRIDGES, NEW JERSEY (SITE 110).

FIG. 4 MONITORING SITE

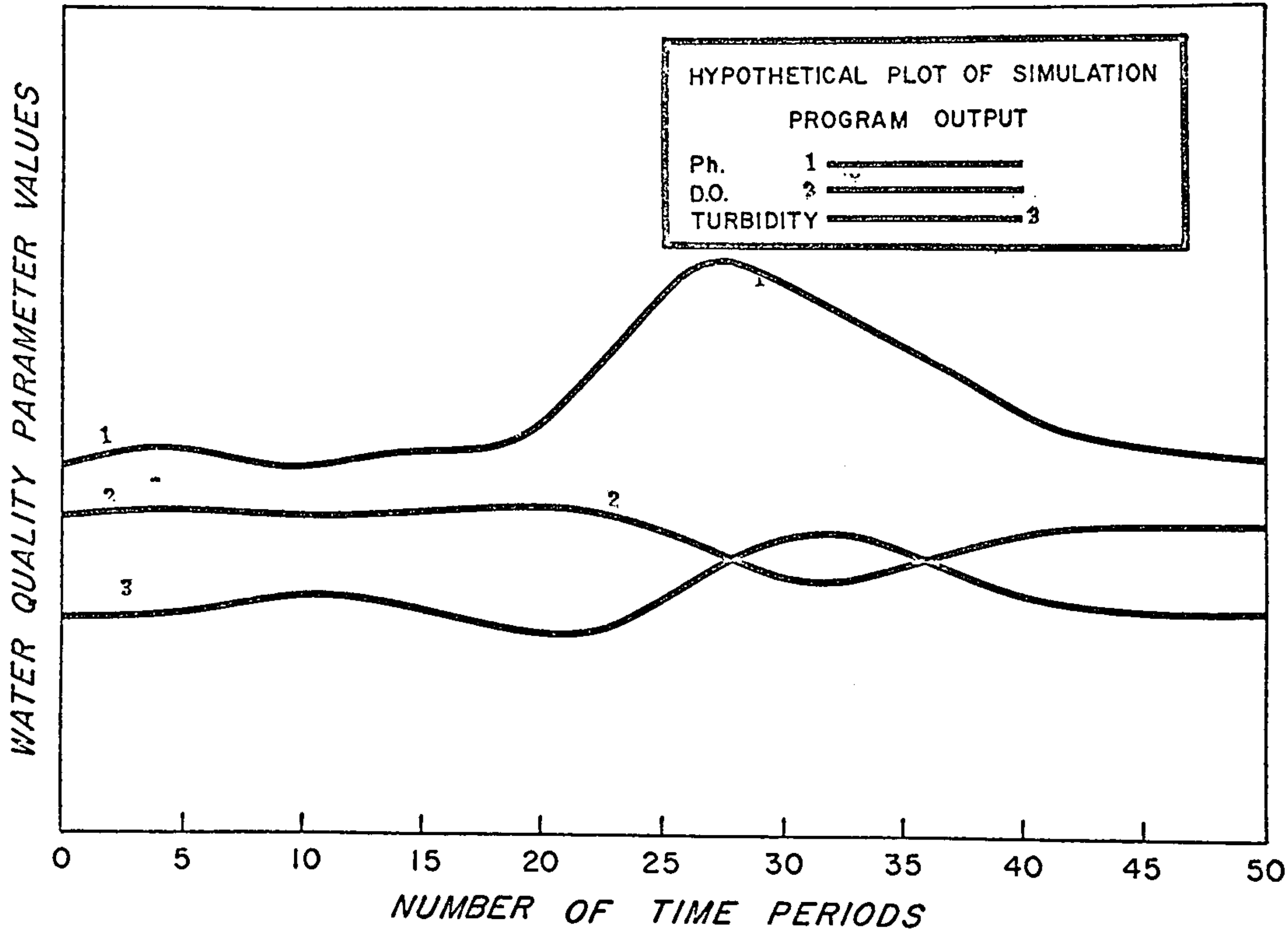
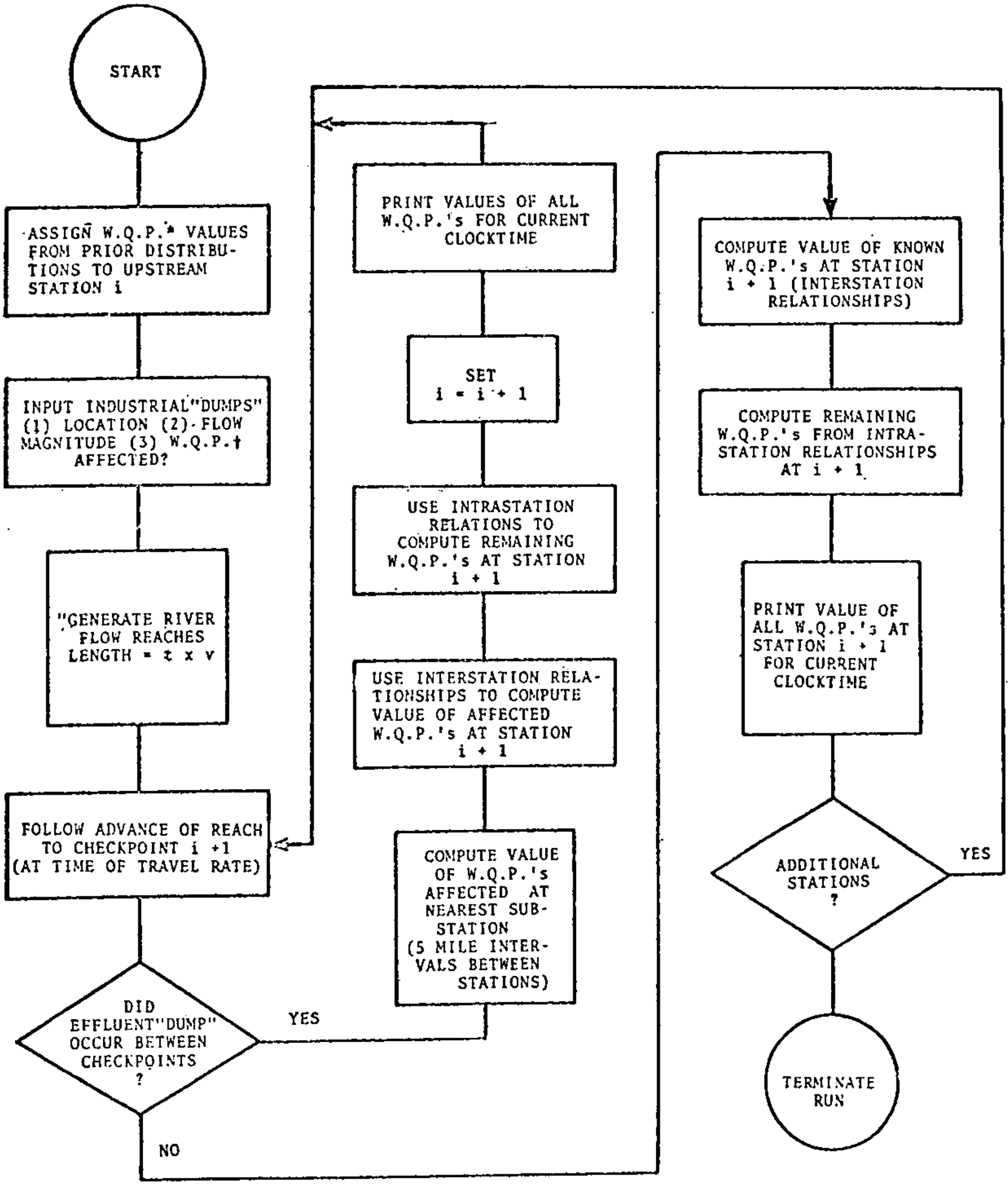


FIG. 5 RESPONSE VS TIME FOR WATER QUALITY PARAMETERS.

FIGURE 6

SYSTEM FLOW LOGIC

COMPUTER SIMULATION MODEL



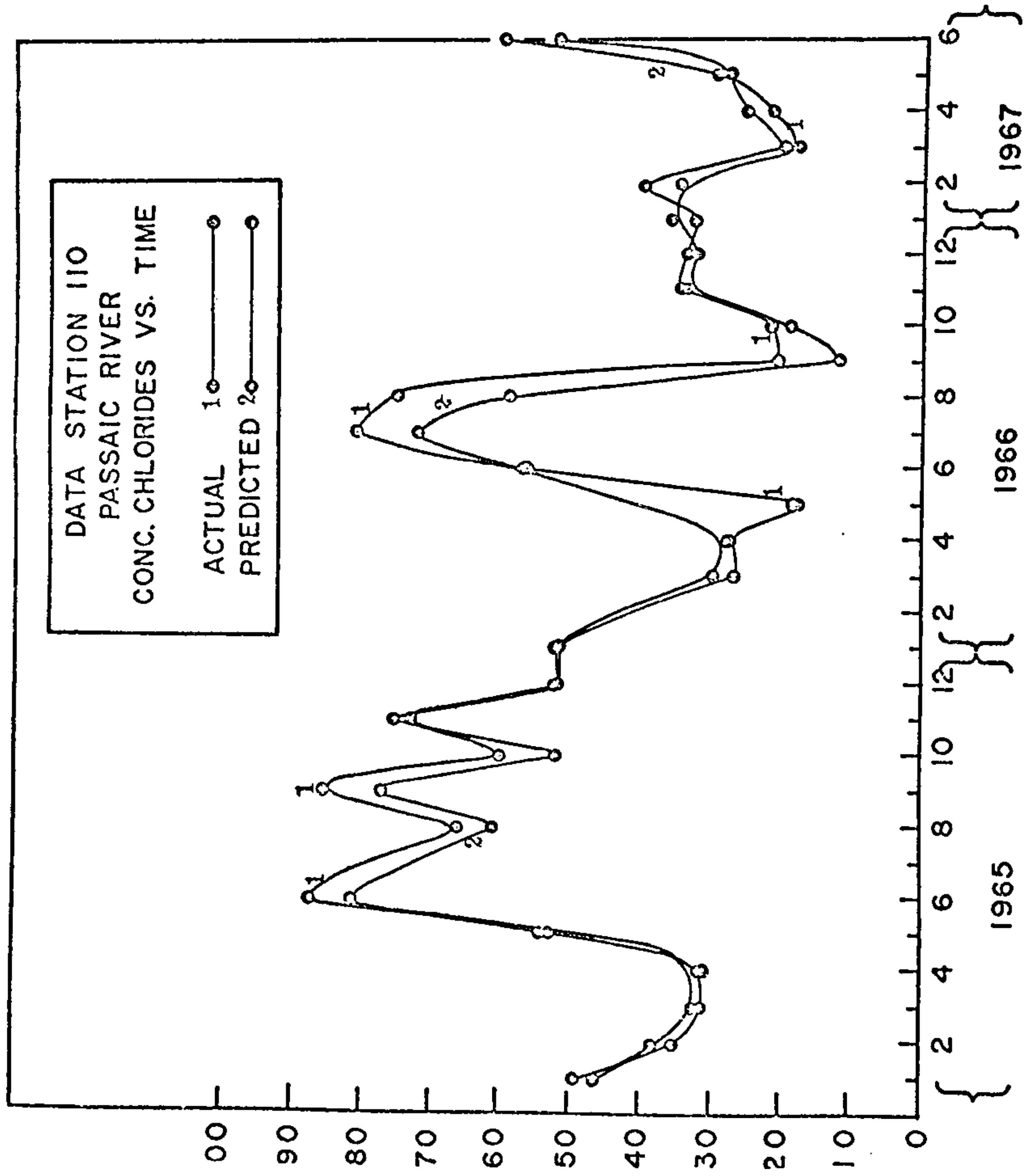
* WATER QUALITY PARAMETER

† INITIAL W.Q. VALUE FROM INDUSTRIAL PROFILE AS APPENDED

t = STANDARD TIME INCREMENT OF RUN

v = TIME OF TRAVEL RATE OF RIVER

FIGURE 7


DATA STATION 110
PASSAIC RIVER
CONC. CHLORIDES VS. TIME
ACTUAL 1
PREDICTED 2
1965
1966
1967

SOME REFLECTIONS ON AN ENGINEERING ECONOMIC STUDY OF THE INDUSTRIAL GROWTH POTENTIAL OF THE UPPER PASSAIC RIVER BASIN

by

ARTHUR LESSER JR., Ph.D.

Professor of Management Science, Stevens Institute
of Technology, Hoboken, New Jersey

This research project was undertaken in 1968 based on a number of beliefs, either explicitly recognized or assumed. Some have turned out to be realistic, others questionable, a few naive, and some simply incorrect. A review of some of the more significant ones will help to explain some of the major conclusions of the study as well as some afterthoughts. A list of beliefs follows, but not in order of importance.

(1) Portions of the Upper Passaic River above Little Falls were heavily polluted.

(2) Measures should and could be taken to clean up the river.

(3) During the cleanup period, industrial growth in the watershed could still continue.

(4) It was a generally agreed upon goal, by society in general, that polluted rivers should be cleaned up as exemplified by the passage of the Federal Water Quality Act in 1965.

(5) The river water quality standards to be formulated by the State and approved by the Federal Government for the Upper Passaic would be definitive and attained within a reasonable period of time, say 5 to 10 years.

(6) The majority of industrial users spewed their effluents directly into the Passaic.

(7) From an industrial and commercial viewpoint, the Upper Passaic River was a desirable place to locate.

(8) The necessary data for the study was available for the asking.

(9) One criterion for the determination of the desirability of an industrial firm locating in the Passaic basin would be the impact of the firm's effluence on the resulting river water quality.

(10) A model could be formulated which would be able to predict the impact of a firm's effluence on river water quality without knowing causal relationships.

(11) Undesirable firms could and would be excluded from the basin.

(12) What, where, when, and how to monitor a river's water quality was known. All that was needed, at most, was its implementation.

The belief has been justified that a model could be constructed to predict the impact of a firm's effluence on river water quality without knowing causal relationships, as is explained in a companion paper by Professor Tirabassi. Other beliefs that have been borne out are: (1) that portions of the Upper Passaic River were, and still are, heavily polluted; (2) commerce and industry find the Passaic basin a most desirable place to locate because of its nearness to markets, skilled manpower, good educational facilities, etc.; (3) the necessary data was available for the asking. (Although the desired data was available, considerable time and effort went into locating it. For example, stream flows at specified gaging stations were available from the U.S. Geological Survey, water quality data was furnished by the Passaic Valley Water Commission, and an inventory of industrial plants in Morris County from the "Morris County Industrial Directory"); and (4) the Upper Passaic could and should be cleaned up.

It was assumed by us that the hue and cry which led to the passage of the Federal Water Quality Act of 1965 represented a national determination to improve the water quality of bodies of water, where necessary. One of the first steps called for by the Act was the adoption by each State of water quality criteria and a plan for applying them to interstate waters within a State. To guard against the temptation of some States adopting loose standards to attract industry, the water quality standards were to be approved by the Federal Government. A significant departure from the past in setting the standards was that they were to be stream standards rather than effluent standards.

A sampling of the standards set by eight States varies from the very specific ones of Indiana and Michigan to vague ones typified by New Jersey. For example, the Indiana and Michigan standards set in 1967 give upper limits on various chemical constituents, whereas the New Jersey standards for fresh water, nos. 2 and 3, provide that they should not affect humans or be detrimental to the natural aquatic biota. Being largely nonquantitative, the New Jersey standards were not suitable for the purposes of this study or use for monitoring purposes. Therefore, the Upper Passaic and its tributaries were segmented and standards set for five parameters based on eight years of water quality data. Where quantitative data was provided in the State standards, such as for pH and D.O., they were used as minima. In short, this study adopted the view that the setting of stream standards was a step in the right direction. However, in retrospect this move does not appear as promising as it once seemed, especially since the relationship between resulting water quality in streams and water quality of effluents is not quantitatively predictable. The question of effluent and/or stream standards needs further study.

Our belief that the hue and cry about cleaning up our rivers would mean reasonably quick and decisive action in New Jersey with special reference to the Upper Passaic turned out to be somewhat naive. However, the obstacles are considerable. Perhaps the most serious is the taxation system wherein municipalities depend principally on real estate taxes to finance their operations. Growing municipalities, as they exist in the Upper Passaic basin, are constantly looking for new sources of funds. A promising source is industry. For example, on December 10, 1969, the Passaic, New Jersey, Herald News pointed out that, "The booming industrial development in Fairfield (N.J.) is a tax assessor's dream." But the newspaper goes on to say that acre after acre of new plants are a nightmare of pollution to the Passaic Valley Water Commission, which draws water from the Passaic, purifies it, and furnishes potable water mainly to the cities of Passaic, Paterson, and Clifton. Each new plant that plans to flow its effluent into the Passaic is required by law to obtain a permit from the Department of Health of the State of New Jersey. Failure to do so means a fine of $100 to $500 per week.* Numerous plants have failed to get such a permit and have suffered no penalties. There is a complaint from an authoritative source that the State has not been aggressive enough in enforcing this law or in forcing waste treatment plants to improve their operations. This source says that 50 out of 117 waste treatment plants on the Upper Passaic are at this time sources of pollution and should be forced to improve their operations by court order. It is rather ironical that a prominent spokesman for the State said that conventional methods have not been successful in cleaning up the Passaic when the conventional methods have not been aggressively used.

The cutback of Federal funds to assist in building sewage treatment plants has also been a severe blow. Many of the 117 plants are both obsolete and too small for present usage. They need to be replaced by regional units, but the governmental units involved are either unable or unwilling to finance them alone. It was estimated in 1968** that it would cost $25,000,000 to $30,000,000 to clean up the Rockaway River alone. It should be pointed out that the New Jersey Department of Health did obtain a court order enjoining the towns along the Rockaway River from any further building in these towns until they establish a regional sewage treatment plant. An example of the economic penalty involved in this move was the suspension of the building of 500 residential housing units, causing the township to lose an estimated $500,000 annually in tax revenues.

The unfortunate conclusion is that there is more talk about cleaning up the river than there has been action. However, this is not an unusual experience in the antipollution effort.

Important experience was gained in operating an electronic continuous water monitor lent by Beckman Industrial Instruments, Inc. The Passaic Valley Water Commission installed it for use during the summer of 1968 at the confluence of the Passaic and Pompton Rivers so that water samples could be drawn first from one river and then from the other. The greatest difficulty in operating the monitor was the constant necessity to clean the probes. They became fouled with algae in two or three days. A review of the data at the end of the summer showed only slow changes, if any, in the seven parameters measured. This observation confirmed the

*The Federal Refuse Act of 1899 provides fines of $500 to $2,500 daily for firms that have not received permits from the Corps of Engineers to flow their effluents into navigable waters (any water body sufficient to float a log at high water).

**"Pollution abatement study for the watersheds of Morris County," pt. 2, Elson T. Killam Associates, Inc., Millburn, New Jersey, December 1968, p. 71 ff.

sampling experience of the Passaic Valley Water Commission, to the effect that continuous monitoring was neither necessary nor worthwhile. This led to the further question: Under what conditions is continuous monitoring essential? More generally it led to the questions: Why, what, where, when, how, and how often should surface waters be sampled? A cursory examination of the literature and conversations with knowledgeable individuals indicated that these questions are largely unanswered. River surveillance appears to be done mostly on an intuitive basis. The overriding reason for this condition is that monitoring had been done previously on effluents, not on the surface waters themselves.

As indicated earlier, the belief that the Upper Passaic should be cleaned up was accepted as an article of faith. From time to time doubting questions arose. Among them were: What benefits will arise from the cleanup and who will receive them? Considering the difficulty of estimating costs of a cleanup, is it possible to arrive at any judgements as to whether the benefits are worth the costs?

According to the FW-2 water quality standards for the Upper Passaic, the river should be suitable as a source of potable water and also for recreational purposes including fishing, the propagation of native fish species for angling, and other fish and aquatic life.

With regard to recreation, many parts of the Passaic and its tributaries are not now desirable for recreation. During the summer the D.O. is much too low to support fish (1½ ppm). At the confluence of the Pompton and Passaic Rivers, the carp in the Pompton turned away from the Passaic water as if there were an invisible physical barrier, a vivid illustration of the quality of the Passaic water. Portions of the Passaic and its tributaries are used now for boating by individuals and by those belonging to clubs. If the Passaic and tributaries were cleaned up to the FW-2 standards, there is a question as to where more people would have access to it, since it is bounded principally by private property. There is a further psychological barrier to overcome, which is that people are not accustomed to think of the Passaic in terms of recreation. However, that is an academic question if they do not have access to it. Unless money is spent to acquire and develop recreational areas, the incremental benefit cost ratio will be miniscule.

A much more convincing argument can be made for the potable water supply. If large sums of additional money spent on pollution control would guarantee against the eventuality of septic river water that cannot be treated at the Passaic Valley Water Commission's conventional water purification plant, a large benefit cost ratio would result. This is because the Commission depends almost exclusively on the Passaic River for its water supply and therefore a septic river would cut off water from thousands of people as well as industrial users. The pertinent question is: Should not the minimum levels needed to guarantee a potable water supply be the controlling criterion for setting standards? It might be added that prior to the imposition of the river water standards, the State Department of Health had approved effluent standards set by the Commission. Another important question is: Was the pollution of the Passaic in 1968 due to the failure of effluent standards to produce "clean water" or to the lack of aggressive policing of the standards? The Commission's water purification engineer says the latter. A case can be made that effluent standards did not have a chance to prove their worth on the Passaic.

As a result of our study, we rejected our original belief that industrial growth could continue while the river was being cleaned up. This conclusion was based on the notion that any added pollution load would be serious since corrective action on other sources of pollution was not being vigorously taken.

Our belief that the majority of industrial users flowed their effluents directly into the Passaic turned out to be incorrect. Most of them flow their effluents into local treatment plants. As pointed out earlier, this has not helped river water quality because of the inadequacies of these municipal waste treatment plants.

The belief that undesirable firms, those that added to the pollution load of the Passaic, would be excluded from the basin also turned out to be incorrect, as indicated earlier.

Our study concluded that industrial growth on the Upper Passaic should be stopped if it will add to the pollution load in the river. The exceptions would be dry industries whose effluents would be little more than sanitary waste, assuming it can be treated adequately, that is at least secondary treatment, and industrial firms that treat their effluents in the same manner. In addition, these effluents should contain no harmful pollutants that cannot be removed by secondary treatment because these pollutants would endanger the potable water supply.

The conclusions of this study are: (1) that water quality standards should be reexamined and set with an explicit knowledge of the environment and the intended "mission" of the stream; (2) further research is needed on the question of stream and/or effluent standards and their interrelationship for setting standards as well as for control purposes; and (3) extensive research is needed on economical stream surveillance methods. One comfort is that more and more well equipped people are becoming actively interested and engaged in working on these problems as well as on others relating to the complex nature of water quality management.

THE BASIC PRINCIPLES AND PRACTICAL CONSEQUENCES OF

A NEW CONCEPT IN STRENGTH OF MATERIALS

(Why did the Arch Concrete Dam of Malpasset
at Frèjus, France, collapse in 1959?)

by

GEORGE REDEY, M.S. in C.E.

Board of Water Supply of the City of New York

The Arch Concrete Dam of Malpasset at Frèjus, France, broke to pieces like an eggshell. The collapse could not be explained by the conservative concepts. With the here-presented new theory, the cause of the catastrophe can be fully explained. Therefore, Columbia University Seminar on Pollution and Water Resources should find it worthwhile to take a closer look at this new concept.

1. Introduction

It is a well-known fact that every material is composed of elementary particles which attract and repel each other. In other words, among themselves or in compounds, the atoms of the elements are exposed to the forces of attraction and repulsion (σ_v, σ_t). The resultant of the two forces is the actual cohesive force, or gravitational attraction ($\sigma = \sigma_v + \sigma_t$). Figure 1 illustrates schematically the specific forces working between atom No. 1 at the origin of the two coordinates and atom No. 2 taken up on the horizontal coordinate at "r" distance from the origin. In the case of an r_o-distance, there is no bond or gravitational force between the two atoms because at this distance the atoms give only heat vibrations.

If atom No. 2 is shifted to the right, we find that first the force of attraction will increase, but after reaching the critical r_I-distance, it will gradually decrease. The intereffect or bond between the atoms which forms the basic material cohesion may be primary or secondary. These two types of bond are essentially determined by the difference between the quantities of energy represented by them or by the distance between the individual atoms. In the case of a primary bond, the distance between atoms is 1-1.5 Å, whereas in secondary bonds, this increases to 3-4 Å. Primary bonds play an important role in the building of molecules; secondary bonds may be considered as intermolecular bonds (between the molecules). The so-called Van Der Waals forces belong to this second category. Their source is the short-period movement of electrons in the atoms where, as a result, constantly fluctuating dipoles are established. (For example, dipoles arise in molecules where the center of gravity of the positive and negative charges does not fall to the same place.)

Previously, the tensile strength of solids was usually explained as being some kind of "material cohesion." Furthermore, it was assumed that there is a connection between the outside forces and movements on the one hand, and the inflicted charges in the internal forces and the deformation of material on the other.

Another basic assumption was that, without outside forces, there is no stress in solids.

On the basis of the above-mentioned circumstances, however, it is easy to see that this concept contradicts itself because "material cohesion" can exist only between different particles, but it does not explain, among other things, the existence of tensile stress; at best it can be set up as an axiom.

To clear up this contradiction, let me present the latest stress theory, which repudiates several concepts accepted as correct for many centuries and throws a new light on the whole complex of theoretical mechanics (see Szabó, 1970).

In the subsequent part of this presentation, let me briefly review the most important theoretical conclusions and practical results of this modern theoretical mechanics.

2. All solids are under continuous stress

The particles of solids are held together by the forces of attraction. The attracting forces press the particles one against the other. Consequently, compressive forces will arise at the surface of contact, and they are in balance with the attractive forces (fig. 2). Naturally, these "attractive-compressive" forces will also be working when the particles are not stressed by outside forces. Therefore, solids are never really unstressed even when they are not engaged by outside forces. At the first reading, this recognition may only have a theoretical significance. But in reality it leads to some far-reaching practical conclusions.

Due to the "attractive-compressive" forces, the particles are always deformed even when they are not stressed by an outside force. The extent of their deformation is different depending on their location in the solid. This is because in the so-called border area (see fig. 3) close to the outside surface the particles are deflected by the undirectional stress at right angles to the outside surface. Deep inside the solid, in the so-called inner core (see fig. 3), much deflection cannot take place because the "attractive-compressive" forces are coming evenly from every direction. Consequently, the center of gravity distance of the individual particles is different in the various areas of the solids.

It was found that the size of the "attractive-compressive" forces is inversely proportionate to the distance of the particles from the center of gravity. This means that, consequently, the "attractive-compressive" forces working parallel to the outside surface are larger, but those working at right angles to the surface are smaller in the border area than in the inner core (see fig. 3).

The "attractive-compressive" forces working dispersed in every direction create internal stresses, or "attractive-compressive" stresses which (in the usual manner) may be illustrated on a stress diagram by the so-called β_o-surface. The shape of these β_o-surfaces is shown in figure 4 for several cross sections most commonly found in practice. (The mean (average) ordinate of β_o-surface is marked as β_o in all three sections.)

The common characteristic of these β_o-surfaces is that the internal stress is greater in areas close to the outside surface and the corners of the cross section than it is deep inside the cross section. This circumstance may be explained by the above-mentioned individual deformation of the various particles and with the different size of the "attractive-compressive" forces. The thickness of the border area depends only on the material composition of the solid; it is not affected by the size of the cross section.

Let us examine now the mechanical model of a material. The material model shown in figure 5 was highly effective in practice, as we shall see in the following part of this study. Therefore, this new theory may lead to expanding natural science with a new branch. (This may be necessary because previously the physics of solids did not devote sufficient time to exploring the characteristics of mechanical stability.)

3. Tensile strength, bending tensile strength, and splitting tensile strength

Mechanical stability is solely and exclusively the result of the above-mentioned own or self-stress ("attractive-compressive" stress) found in solids.

In the course of a gradually increasing tensile stress, the own or self-stress ("attractive-compressive" stress) will also gradually decrease; at every point breaking will occur when the attractive and compressive stress is reduced to zero. This means that the greater the own or self-stress ("attractive-compressive" stress) of the solid during the original unstressed condition, the greater its tensile resistance. Therefore, the β_o-surfaces illustrate simultaneously beyond the distribution of own or self-stress ("attractive-compressive" stress) the distribution of tensile strength in the cross section. Consequently, the extent of the tensile strength is <u>not</u> the same at every point of the cross section. Tensile strength is not a constant factor of the material; it is not a scalar, but, rather, a vectorial quantity.

The value of the so-called centric tensile strength $\beta_n = P_{sz}F$ is equal to the mean ordinate (β_o) of β_o-surface: $\beta_\Delta = \beta_o$. This mean ordinate is greater in small cross sections than in large ones, because, as mentioned before, the thickness of the border area showing higher tensile resistance is always the same in the same material. Therefore, the same thickness has a greater significance in small cross sections than in large ones. Consequently, the value of the so-called centric tensile strength also depends on size of the cross section: the value is greater in small cross sections than in large ones.

The so-called "bending-tensile" strength β_{sz} is equal to the mean border ordinate of the β_o-surface because, in the case of bending, the tensile strength of the outer filaments in the border area will determine the working load of the cross section: $\beta_{sz} \cong \beta_o^r$ (see fig. 6). Therefore, the bending tensile strength is always substantially greater than the centric tensile strength.

The so-called "splitting tensile" strength β_{st} is equal to the mean ordinate of the inner core of β_o-surface because, in the case of a splitting resistance test, the tensile strength of the inner core will determine the resistance of the cross section: $\beta_{st} \cong \beta_o$ (see fig. 7). Therefore, the splitting tensile strength is always a little smaller than the bending tensile strength.

4. Shearing strength and torsional shearing strength

The shearing strength of various materials is attributed to the friction between the particles. As stated before, the own or self-stress ("attractive-compressive" stress) presses the particles one against the other. In the case of tangential stress, therefore, friction may arise along the contact points of the particles; this friction is called the shearing strength of the material. As we know, the size of the friction is equal to the normal force multiplied by a " μ " friction coefficient. The normal force, which in our case is the own or self-stress ("attractive-compressive" stress), is not constant at every point of the cross section (see fig. 4). Therefore, the shearing resistance of the material cannot retain the same value at every point. When multiplying each ordinate of β_o-surface by μ factor, we shall obtain the distribution diagram of the shearing stress (the so-called $\mu\beta_o$-surface; see fig. 4). This shows that the shearing stress is not constant in the same material, and that it is not a scalar but rather a vectorial quantity. In the case of simple shearing stress, the shearing strength of a cross section is determined by the mean ordinate of the $\mu\beta_o$-surface. Of course, the value of the ordinate depends again on the size of the cross section. Consequently, the shearing strength must also be determined by the size of the cross section, which means that the shearing strength of small cross sections is greater than that of large cross sections.

The so-called torsional shearing strength is greater than the simple shearing strength because--as we know--in the case of torsional stress, the shearing strength of the border area determines the loading capacity of the cross section and it is always greater than the average ordinate of $\mu\beta_o$-surface (see fig. 4).

5. Compressive strength

The new concept leads to an even more surprising and important observation in connection with the compressive strength. In the case of compression stress, the material always breaks along a surface with a certain angle of inclination because the overstress of the shear and rupture (breaking) strength of the material. (See picture of compression failure in fig. 8.)

Naturally, the shape of the compression failure and the distribution of forces have a decisive influence on the size of the breaking force. This shape of compression failure is different for each solid shape. It means that a different breaking force and compressive strength is attached to each solid shape and solid size. For example, it can be early proved that in the case of a rectangular cross section the longer the form of the cross section, the smaller the compressive strength (see fig. 9), assuming of course that the height of the tested material remains the same.

The dependence of the theoretical compressive strength on the shape of the cross section is very substantial; for example, in concrete. The theoretical compressive strength is also affected by the height of the test material and its absolute size. This shows that the compressive strength, similarly to the other types of strength, is not constant in a given material.

6. Practical consequences

According to the new theory, as indicated above, each kind of mechanical strength--tensile, bending, splitting, shearing, torsional, and compressive--depends to a very considerable extent on the size, shape, and height of the test material. This fact should be taken into consideration when determining the permissible or critical stresses (some countries base their calculations on the permissible stress, others on the critical stress). For many types of stresses, the permissible or critical stress value could be set at a substantially higher level in small cross sections than in larger ones. The compressive stress of circular and rectangular cross sections could be set higher than that of long-shaped cross sections. Let me demonstrate this by a few examples on concrete structures.

Following the principle of equal safety margins, the permissible or critical stresses should be correspondingly determined according to a gradual scale. For example, for tensile strength, bending tensile strength, and splitting tensile strength the permissible or critical stress values should set at different values, because the bending tensile strength of the concrete (see table 1) is always 50 percent greater than its tensile strength, and the splitting tensile strength of the same concrete is approximately 5-10 percent smaller than its tensile strength. In the case of larger cross sections, substantially higher shearing stress could be permitted for torsion than for shearing.

The dependence of compressive strength on the shape of the cross section has an extremely great practical significance. As shown by table 2, if B/D = 5, the theoretical compressive strength is only one-half the strength of the $7^7/_8$-inch cube. Therefore, concrete walls exposed to centric stress--naturally, these walls are usually constructed with a long-shaped cross section--always have a much smaller safety margin against breaking than previously believed. (See fig. 11 and fig. 12.) By an interesting coincidence, most of the experimental results prove that logically and mathematically this theory was correct. Particular attention must be called to the dependence of compressive strength on the shape of the cross section. In the case of long- and narrow-shaped cross sections, the theoretical compressive strength may attain only one-fourth of the cube strength. This means that in these types of cross sections the theoretical compressive strength is barely larger--sometimes it may be even smaller--than the permissible compressive strength. Consequently, the safety factor is barely greater than one in such structures. An unfortunate proof for this was furnished by the catastrophic collapse of the 197-foot-high concrete dam at Frèjus in Southern France which occurred in 1959 (see fig. 13).

The quality compressive strength of the concrete used for this dam was 6400 psi; the calculated compressive stress (centric pressure) at the time of the catastrophe came to approximately 1294 psi. At this computed compressive stress, the concrete dam broke to pieces like an eggshell.

This collapse could not be explained by the earlier concepts. According to the new theory, however, the theoretical compressive strength is set at 1237 psi for the very long and narrow cross section of this dam. This makes the catastrophe fully understandable. This undoubtedly means that the permissible or critical stresses for centric pressure should be set at a graduated scale (see table 2). Additionally, the previously established safety factors should be also recalculated.

This modern theory explains from a different angle--and throws a new light on--the phenomena of flow, rehardening, contraction, tensile and breaking strength, the strength, the strength ratios of cubes, prisms, and cylinders. It also explains the relationship between compressive strength and bending or splitting strength, for which it also delivers the mathematical proof.

7. Contraction and slow deformation (creeping)

The affinity of contraction and slow deformation has been known for a long time. The new theory offers a very simple explanation to this phenomenon: contraction is the same as the slow deformation of a material, unstressed by outside forces, under the effect of the β_o-stress. The new theory is also supported by the observation that, generally speaking, the full contraction, creeping deformation of the concrete is approximately equal to the slow deformation of the test material stressed by a compressive force corresponding to the value of breaking strength. However, the results of the large number of experiments do not fully agree with the theory, mainly because the outside stress cannot be simultaneously applied with the β_o-stresses since β_o-stresses arise only in the course of contraction, and stressability requires a certain amount of strength.

The contraction of concrete is usually attributed to the drying out of concrete structures. But contraction takes place also in materials which do not contain water (for example, in synthetic resins). It is also possible that in the case of other materials, it is completed within a very short time (in iron, for instance, during the period of cooling down). Therefore, the previously accepted concepts of contraction should be reconsidered.

8. Result of abrupt changes in the section

When shaping solids, at the place of interrupting the continuity of the material--where the β_0-stresses are also terminated by the cutting--they follow a similar pattern as if stopping an outside load equal in size to the β_0-value; therefore, the solid is deformed additionally, the isotropy comes also to an end in the vicinity of the cutting because the originally constant β_0-stresses are changed. This conclusion shows, therefore, that the introduction of β_0-stresses means more than a simple coordinate transformation.

To illustrate the above thesis, let us investigate the behavior of a circular-shaped bar weakened by a cut (see fig. 14). The effect of the notch may be taken into consideration by assuming that the stress working at the new surface is equal in value to the β_0-stress. In this investigation it is not necessary to satisfy the conditions of equilibrium with the usual strictness because the equilibrium of the bar as a whole is guaranteed regardless of the weakening. Therefore, when investigating, for example, the X-X cross section, it is sufficient to examine an r-long piece in the area of the cross section.

The resultant of β_0-stresses working in the "r" section is:

$$\Sigma K = -\beta_0 \frac{d_K + r\cos\vartheta}{2} 2\pi r = -\beta_0 \pi r (d_K + r\cos\vartheta)$$

The stress caused by this resultant in the X-X cross section may be expressed by the following equation:

$$\beta_0' = \frac{\Sigma K \cos\vartheta}{s} = \beta_0 \frac{4r\cos\vartheta(d_K + r\cos\vartheta)}{d_K^2} \left(\frac{d_K \pi}{4}\right)$$

In view of the fact that the β_0-stress was working in the X-X cross section from the very beginning, the stress at the notch is:

$$\beta_K = \beta_0 + \beta_0' = \beta_0\left[1 + \frac{4r\cos\vartheta(d_K + r\cos\vartheta)}{d_K^2}\right]$$

The K sin ϑ components forming a right angle to the bar axis cause shearing stress which can also arise from the fact that the β_0-stress gradually decreases by moving away from the X-X cross section. These stresses, however, do not substantially influence the behavior of the bar.

As mentioned above, we cannot talk of an isotrop material after the completion of the notch.

From our discussions, it follows that the ultimate tensile stress of the X-X cross section will increase to:

$$\beta_{sK} = -(\beta_0 + \beta_0') = -\beta_K$$

From the ratio of the increased and the original tensile stress:

$$\frac{\beta_{szK}}{\beta_{sz}} = 1 + \frac{4r\cos\vartheta(d_K + r\cos\vartheta)}{d_K^2}$$

We can conclude that, in addition to the known ϑ-angle, its value also depends on the unknown r-distance. Experiments have indicated that, when using the customary steel test rods, the r-value may be put at 1.5-2 mm.

The above example shows that, with the help of the new theory, so far unsatisfactorily explained phenomena may be easily understood.

9. Strength of variously shaped test materials

With the new stress theory, we can also easily explain the different strength of variously shaped test materials when they cannot move laterally. For example, the breaking strength of a quadratic prism (fig. 15) may be determined as follows:

The breaking strength is composed of two parts

$$\beta_P = \beta_P' + \beta_P''$$

where $\beta_P = 6{,}31\,\varrho^{1,74}\cdot\beta_s$ is the compressive strength computed in Szabó (1970, p. 61), and β_P'' is the increase in strength caused by the prevention of lateral movements, which is a function of the tensile strength of the frame-shaped solid body illustrated by figure 15.

According to figure 15, the forces working on the frame-shaped body indicate the following correlation:

$$\frac{P_h}{2} = \frac{\Delta P}{4}\,\mathrm{tg}\,(\gamma_0 - \varrho)$$

where P_h is the horizontal force acting on one-fourth of the frame-shaped body, ΔP is the increase of the breaking force, γ_0 and ϱ as on figure 15.

The tensile strength of a cross section of the frame-shaped body is:

$$P_{sz} = \beta_0 \frac{B^2\,\mathrm{tg}\,\gamma_0}{4}$$

But at the moment of breaking

$$\frac{P_h}{2} = P_{sz},$$

therefore

$$\Delta P = \beta_0 \frac{B^2\,\mathrm{tg}\,\gamma_0}{\mathrm{tg}\,(\gamma_0 - \varrho)}$$

from this

$$\beta_P'' = \frac{\Delta P}{B^2} = \beta_0 \frac{\operatorname{tg} \gamma_0}{\operatorname{tg}(\gamma_0 - \varrho)}$$

and the theoretical compressive strength of the prism is:

$$\beta_P = \beta_0 \left[6{,}31 \varrho^{1{,}74} + \frac{\operatorname{tg} \gamma_0}{\operatorname{tg}(\gamma_0 - \varrho)} \right]$$

It should be noted that the value of β_p is somewhat reduced by relatively small bending stresses acting on the frame-shaped body.

The strength of a cylinder--when ignoring the above-mentioned small bending stresses--is equal to the strength of a quadratic prism.

Following the above steps and procedure in determining the breaking strength of a "B" wide and "A" long rectangular prism (wall body), the following values will be obtained:

$$\beta_P = \beta_0 \left[6{,}31 \varrho^{1{,}74} + \frac{B}{2A - B} \cdot \frac{\operatorname{tg} \gamma_0}{\operatorname{tg}(\gamma_0 - \varrho)} \right]$$

This equation shows that the greater the A/B ratio, the smaller the breaking strength. In the case of an infinitely long rectangular prism, the second member of the above equation--representing the additional strength due to the prevention of lateral movements--becomes zero.

In this article, we discussed the strength of test bodies where $H \geqq B \operatorname{tg} \gamma_0$ and, therefore, the breaking strength is developed as illustrated in figure 15. However, the possibility to determine also the breaking strength of lower prisms such as that of the cube follows:

$$\beta_K \simeq \beta_0 \left[\frac{2 \operatorname{tg} \varrho}{1 - \operatorname{tg} \varrho} + \frac{1}{\operatorname{tg}(45^\circ - \varrho)} \right]$$

10. Conclusions

We must assume that, between the elemental particles of solids, there are certain attractive forces and--at the contact points--also some counterbalancing repulsive forces. This assumption leads to the following conclusions:

(1) Solids are always under stress, even in unloaded condition.

(2) The previously known stress calculations have only determined the change of the stress; they failed to compute the real value of the existing stress because there is no tensile stress but only compressive stress of various extent.

(3) There is no basic difference between tensile and compressive loadup condition.

(4) All static values are in direct proportion to the β_0-stress affecting the material in unloaded condition.

(5) Additionally, the value of the shearing and crushing strength also depends on the "φ" angle of inside friction, which is an unknown factor and, consequently, its value must be determined by a series of tests.

(6) Finally, it is very important to recognize that, along the outside surface, the shape of the elemental particles of solids undergoes a certain change effected by the "attractive-compressive" forces. The nature and size of this change differs from the change affecting the inner particles of the body, because in the so-called border area the particles can be deflected in the direction of surface. Consequently, the β_0-values characteristic of the prevailing "attractive-compressive" stresses may be illustrated by a distribution diagram drawn along a selected cross section, which diagram is flat in the inner side of the cross section, shows a rising curve toward the surface, and takes a pointed shape at the edges of the cross section.

Reference Cited

Szabó, G., 1970, Grundlagen einer festigkeits theorie (The basic principles of a strength theory): Bauverlag, v. I, GMBH, Wiesbaden-Berlin.

References Recommended

Branderburger, 1948, Neue theorie der elastizität und festigkeit (New theory of elasticity and strength): Zürich, Schweizer Druck und Verlagshaus.

Department of Defense, 1962, Shelter design and analysis, v. 1, Fallout protection: Civil Defense Office, Wash., D.C.

Elwyn, George, 1957, Large basic reinforced concrete design: Elastic and creep: New York, Ronald Press.

Grengg, 1960, Die lehre der talsperrenkatastrophe Malpasset, Frèjus (The lesson drawn from the catastrophy of the Malpasset, Frèjus water dam): Der Bauingenieur Jahrgang.

Palotás, 1959, Epitoanyagok I (Building materials I): Budapest, Hungary.

Popovics, 1967, Relation between various strength of concrete: Highway Research Record, no. 21, Wash., D.C.

Urquhart, L. C., O'Rourke, C. E., and Winter, George, 1958, Design of concrete structures: New York, McGraw-Hill.

Table 1.--Theoretical stress values

(Computed for a square-shape concrete test piece with 4275 psi compressive strength tested for 28 days, 7-7/8" wide x 7-7/8" high, and "a"-variable long (see fig. 10). 1 kg/cm^2 = 14.2234 psi).

a	Tensile-	Sheering-	Torsional-Shearing -	Bending - Tensile-	Splitting-Tensile-
	Strength				
inch	psi				
2.4	485	360	368	615	440
4.0	410	308	351	575	371
7.9	346	256	351	521	371
15.8	304	224	351	460	292
39.4	283	204	351	426	278

Table 2.--Theoretical compressive strength (β_o)

(Computed for a rectangular-shape concre-e test piece with 4275 psi compressive strength tested for 28 days, and a B/D cross section where "D"-thickness of the test piece is 7-7/8" and its "H" height is also 7-7/8" (H = D). 1 kg/cm^2 = 14.2234 psi).

D		H/D=1.0				H/D=1.5				H/D=2.0			
		B/D=				B/D =				B/D=			
cm	inch	1.0	2.0	5.0	12.0	1.0	2.0	5.0	12.0	1.0	2.0	5.0	12.0
		psi											
6	2.36	6000	3610	2830	2520	3700	2080	1580	1395	3480	1960	1510	1310
10	3.94	5100	3100	2420	2180	3150	1780	1355	1225	2950	1695	1300	1140
20	7.87	4275	2680	2120	1926	2650	1550	1190	1085	2480	1470	1140	995
40	15.74	3760	2420	1940	1792	2530	1395	1085	1010	2180	1325	1040	940
100	39.40	3500	2880	1800	1710	2160	1310	1025	955	2040	1255	995	898
500	197.00	3330	2190	1792	1670	2060	1270	995	940	1935	1200	970	870

Figure 1. The forces working between atom Nos. 1 and 2.

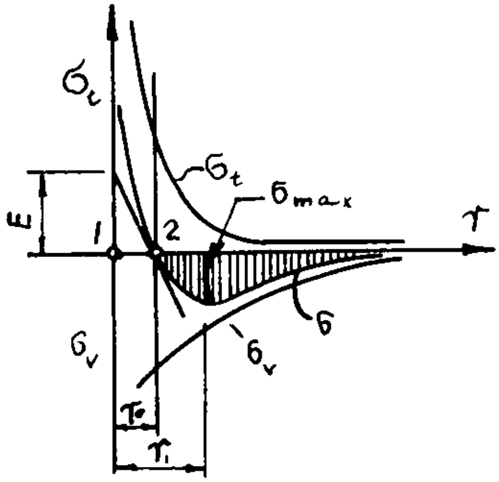


Figure 2. Attractive and compressive forces under different stress conditions.

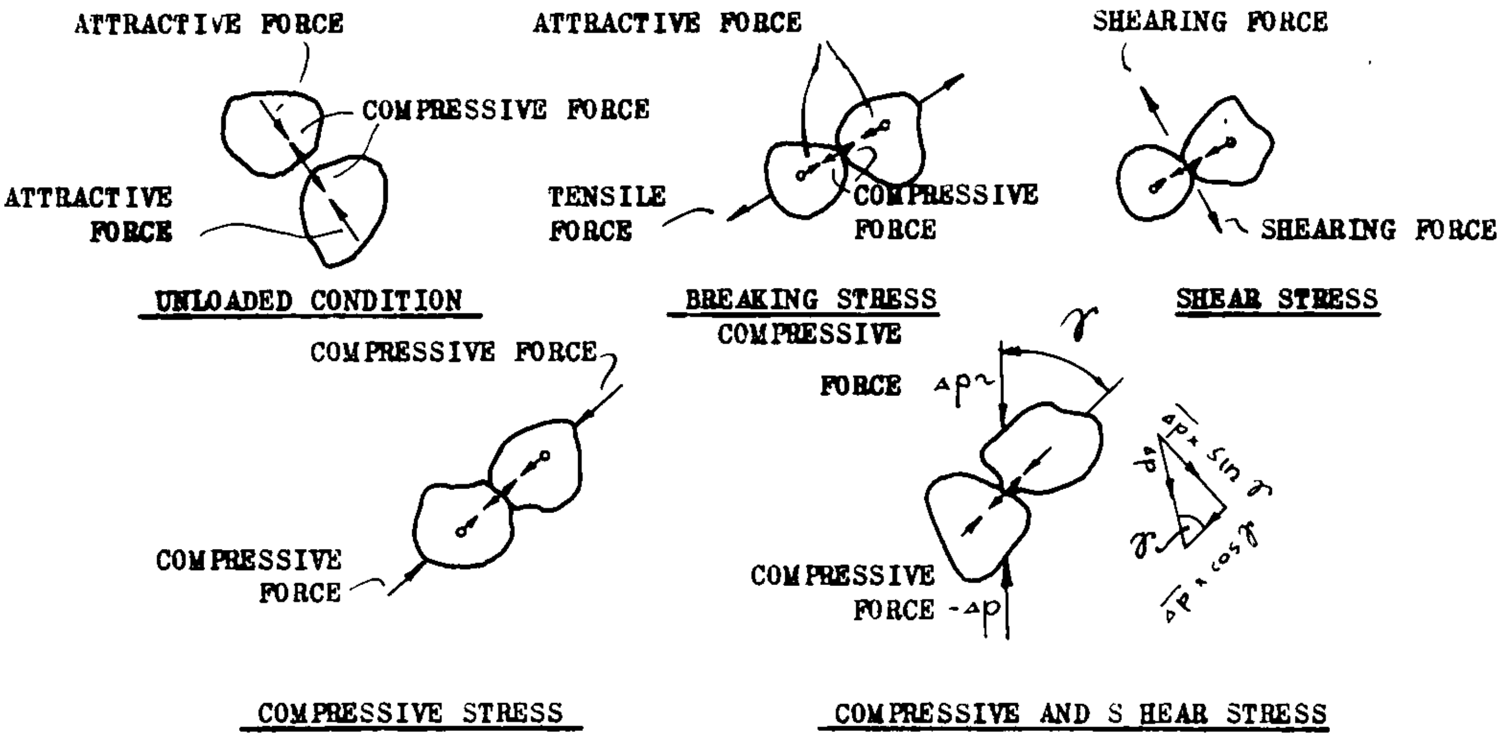


Figure 3. Selection of forces by location.

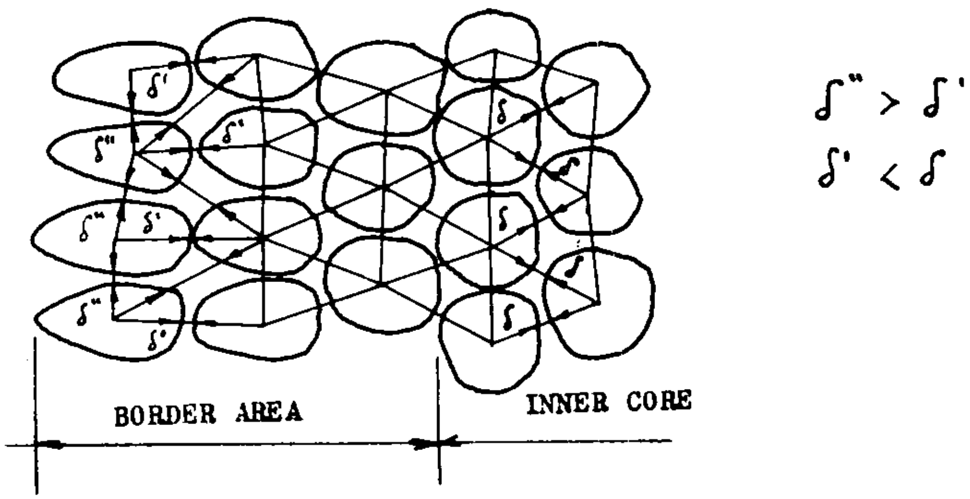


Figure 4. Stress diagrams of internal forces. The mean (average) ordinate of β_0-surface is marked as β_0 in all three sections.

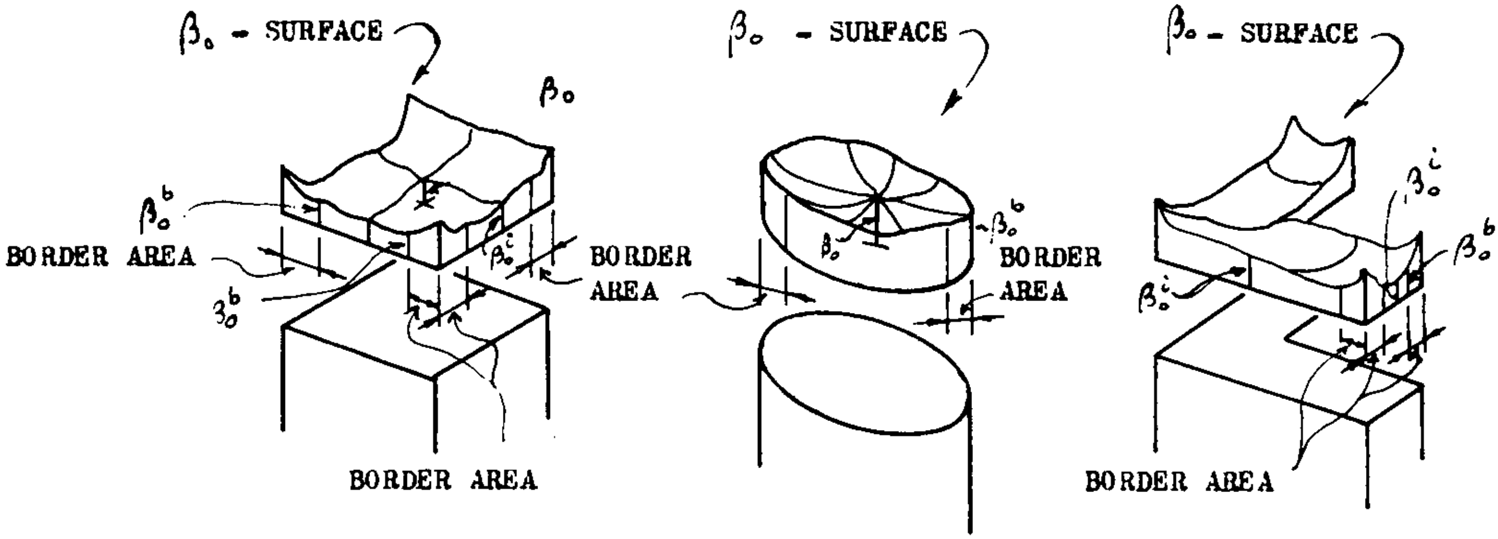


Figure 5. Stresses found in the different cross sections of a cubic solid body.

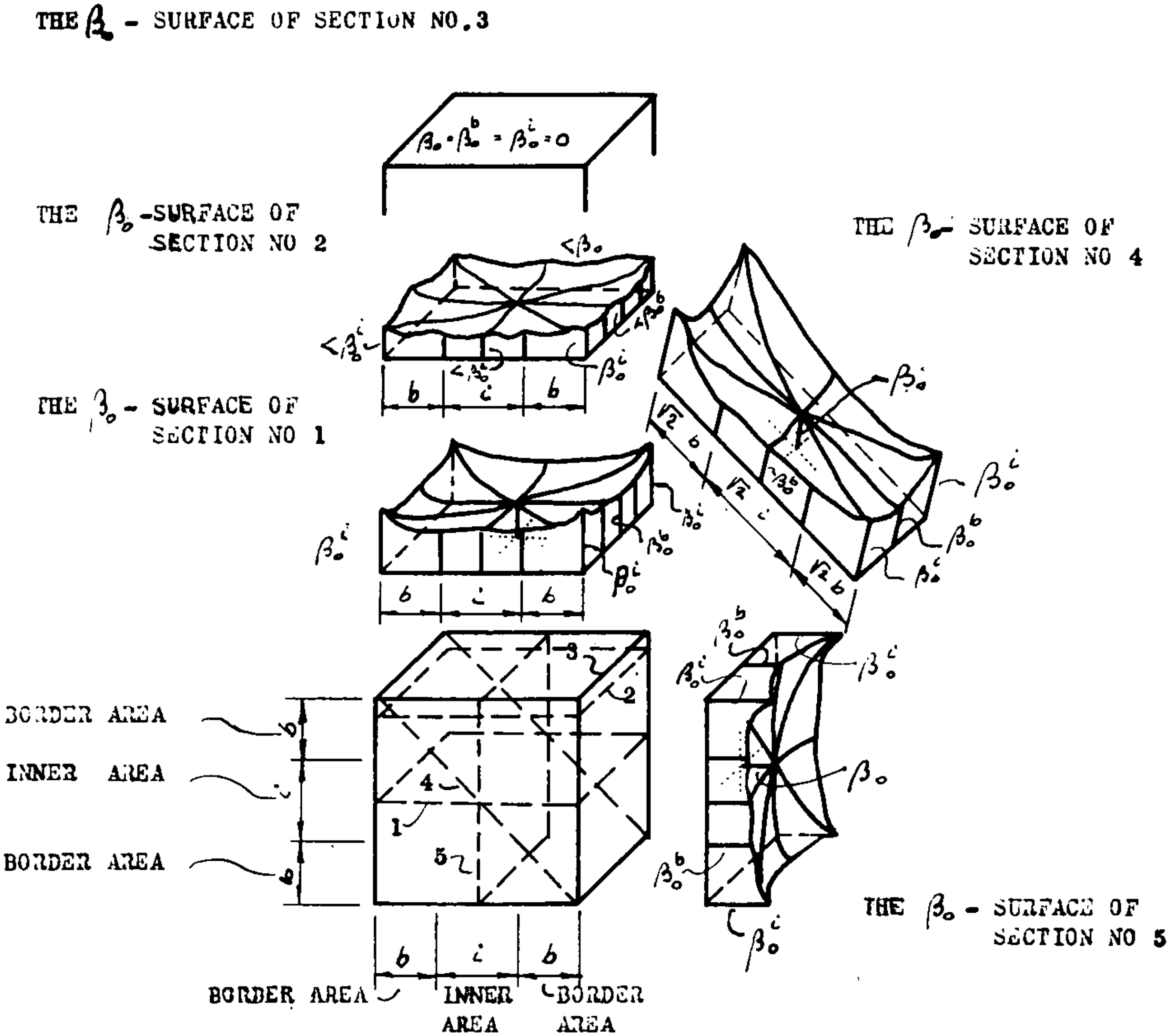


Figure 6. Diagram of stresses and strength under loads.

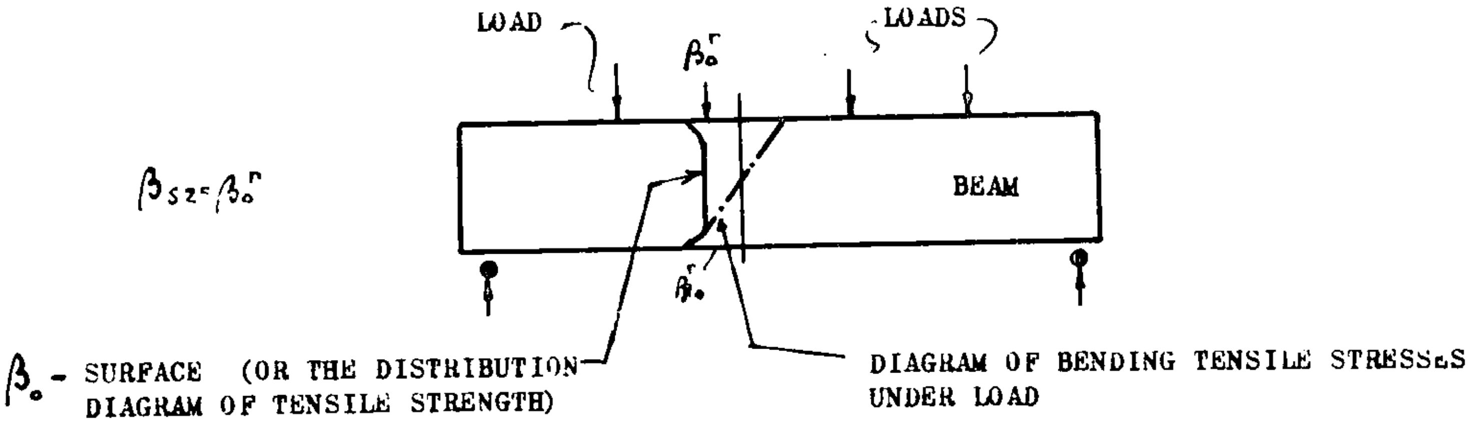


Figure 7. Diagram of splitting stress.

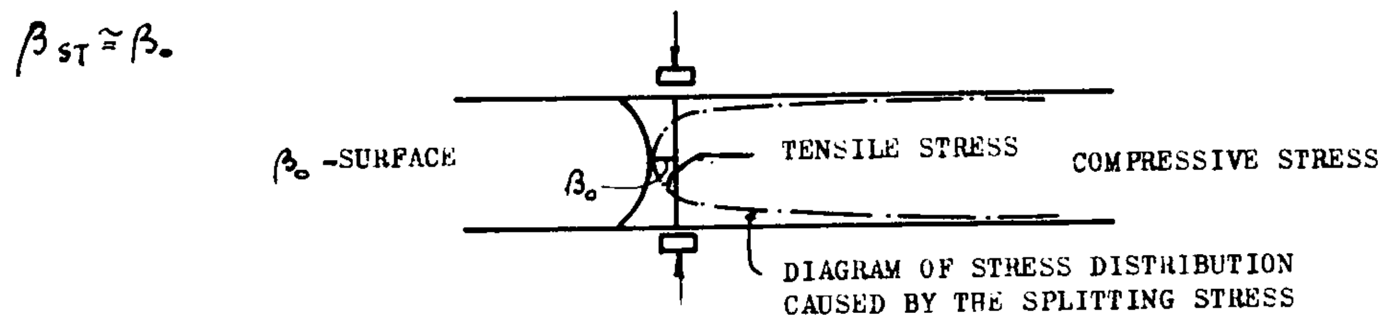


Figure 8. Picture of compression failure in the case of a cylindrical test material.

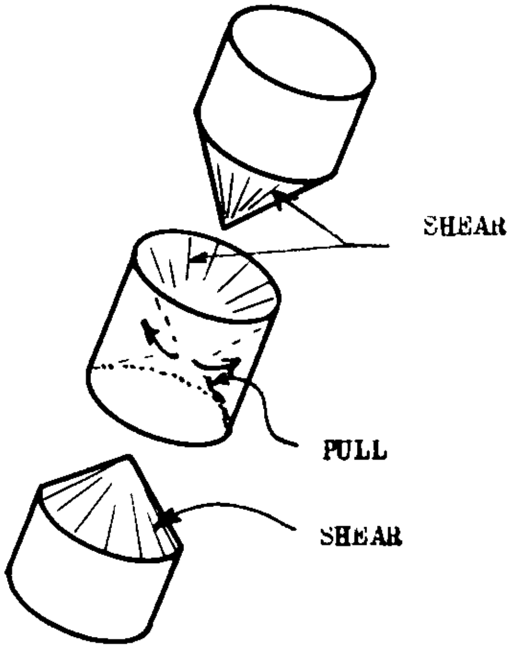
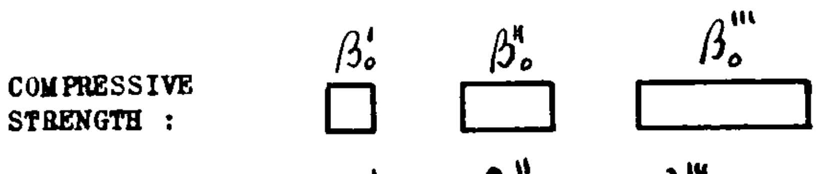


Figure 9. Rectangular cross section shape bodies with increased length for compressive strength test.



$$\beta_0' > \beta_0'' > \beta_0'''$$

Figure 10. Square shape concrete test piece.

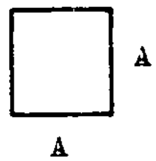


Figure 11. Variation of compressive strength.

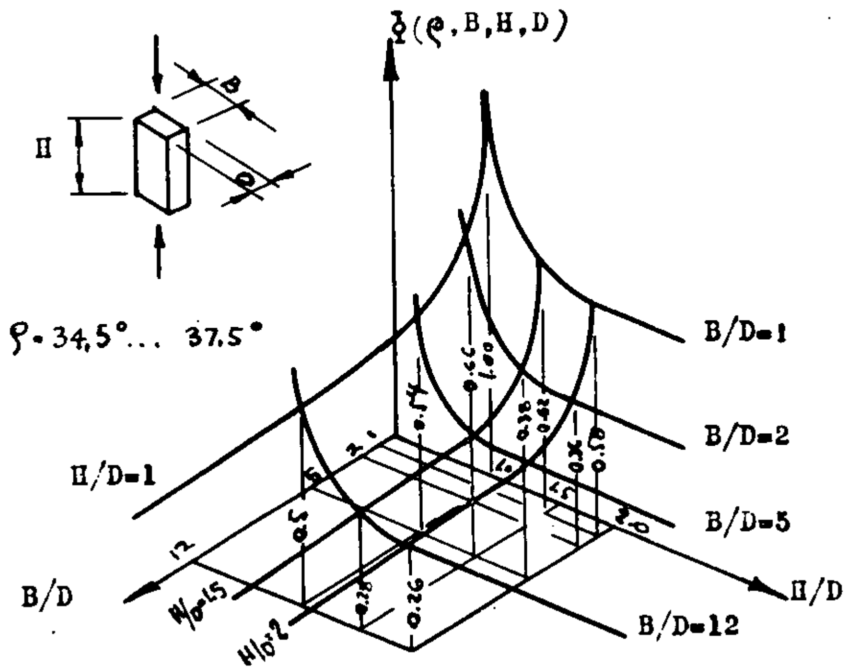


Figure 12. Rectangular shape of concrete body to table 2.

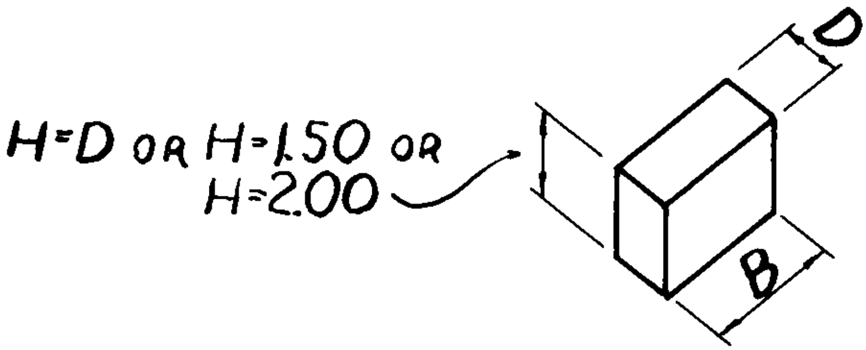


Figure 13. The Arch Dam of Malpasset at Frèjus, France.

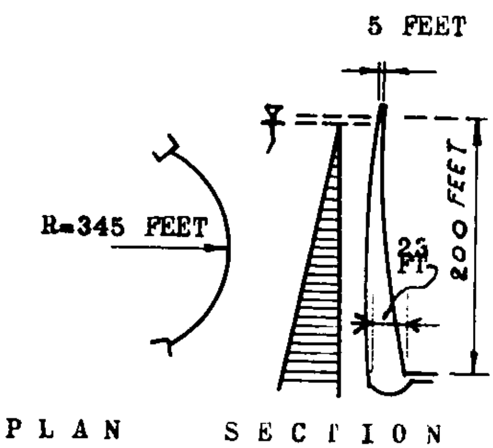


Figure 14. Stress increase at cross section of a circular bar weakened by a cut.

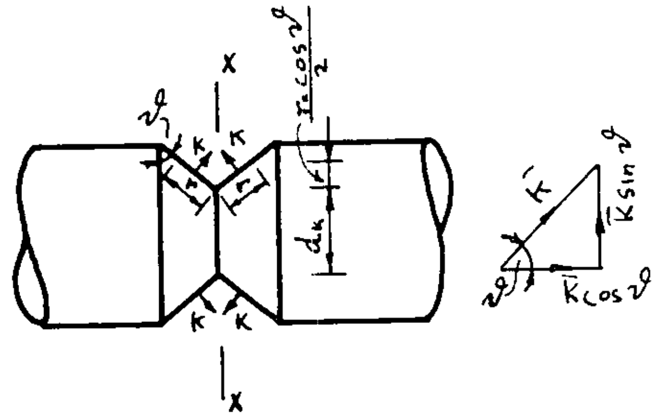
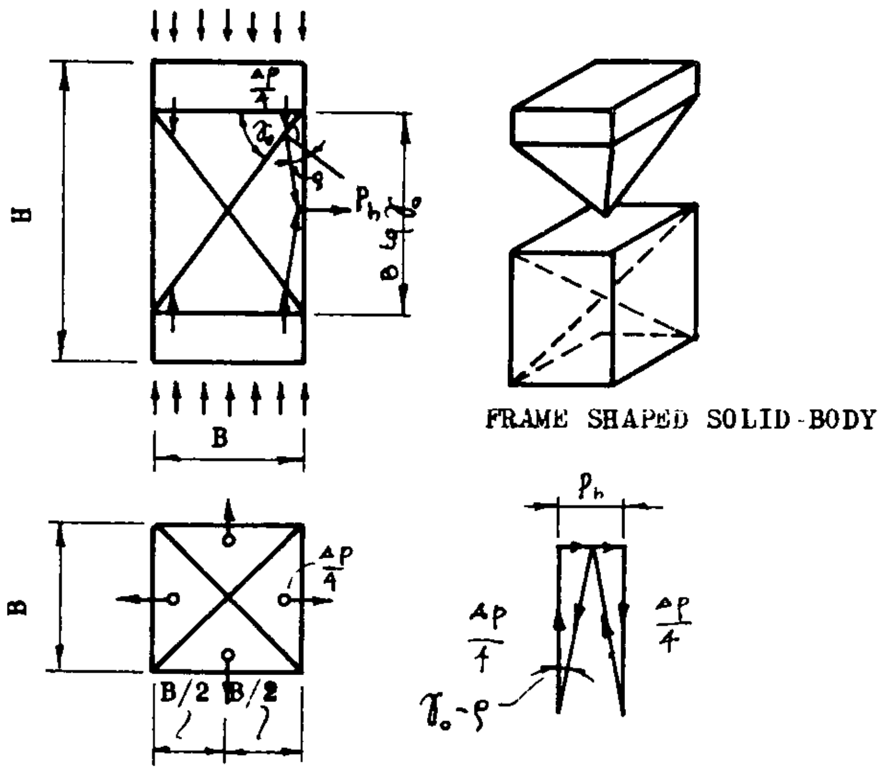


Figure 15. Breaking strength of a quadratic prism.



Definition of symbols

Å	Angstrom unit, 0.1 μ or 10^{-8} centimeter
F	Area of section
$\overline{K}$	Stress for a linear foot on perimeter
ΣK	The resultant stress of the β_o-stresses
P_h	Acting horizontal force on one quarter of the frame
P_{UT}	Ultimate tensile force of a section of the frame
P_T	Tensile force on section
ΔP	The increase of the breaking force
d_K	The decreased diameter
Δ_p	Outside compressive force
r	Distance
β_o	Designation of stress diagram surface or magnitude of various stresses
β_{o_b}	Magnitude of stress at center or centric stress
β_o	Magnitude of stress at border area
$\beta_o{}^i$	Magnitude of stress at inner area
β_K	Activated stress of K
β_o'	Stress on section X-X
β_{BT}	Bending-tensile stress
β_p	Theoretical ultimate compression stress on a cubic shape test prism
β_{st}	Splitting-tensile stress
β_{UTK}	Ultimate tensile strength
β_T	Centric tensile strength
γ, γ_o	Angle
δ, δ', δ''	Attractive-compressive force
ϑ	Angle of a cut on the bar

μ	Factor of friction
ϱ	Interval friction of material or angle
σ	Resultant force of attraction and repulsion forces of atoms
σ_t	Repulsion force of atoms
σ_v	Attractive force of atoms

WHAT'S HAPPENING TO LAKE ERIE?

by

JOHN A. JONES, Ph.D.

Miami-Dade Junior College

(Former Acting Director, Lake Erie Environmental Studies, State University (New York) College at Fredonia, 1968-1970)

Introduction

Nearly a decade ago, on October 20, 1961, Dr. Stanford H. Smith of the U.S. Bureau of Commercial Fisheries Great Lakes Laboratory at Ann Arbor described Lake Erie as "a dying lake" to a small group of citizens. The press in Cleveland seized upon his statement to express the frustration of an urban population forced to reach farther and farther out into the lake for their drinking water, drive greater distances to find clean beaches, and seek alternative sources of protein (or income) for the sports and commercial fisheries. Dr. Smith (1969) admits that he might have gotten "a little too emotional" with his statement, but the comment drew the world's attention to an infamous example of a polluted, misused water resource.

Besides Smith's early work, others have documented the deterioration of Lake Erie and the other Great Lakes. Early notice of the effects of pollution was taken around the urban areas of Detroit and Toledo (Hunt, 1962) and Cleveland (Davis, 1964). Beeton (1965) documented changes in the physical, chemical, and biological characteristics of the lakes occurring during the 20th century. The Federal Water Pollution Control Administration (1968) drew heavily on Beeton's work for the controversial "Lake Erie Report." Fisheries decline in Lake Erie through 1966 has been traced by Smith (1969) and Applegate and Van Meter (1970).

Characteristics of the Great Lakes

The Great Lakes constitute the largest single mass of fresh water in the world, ultimately discharging over 7000 m^3/sec of water through the St. Lawrence River, draining the wastes of 30 million people (40% of the total U.S. population), and supporting the industries which provide 30% of the U.S. Gross National Product.

During the 19th century, the lakes had total dissolved substances concentrations of about 100 ppm (mg/kg of water), oxygen concentrations near saturation at all depths throughout the year, limited abundance of plankton, and predominantly coregonid and salmonid fish populations (Chandler, 1964 and Beeton, 1965).

The lakes essentially drain from one to another (fig. 1), Lake Superior lying over 180 m above sea level, Lakes Michigan, Huron, and Erie about 175 m above sea level, and Lake Ontario about 75 m above sea level (Ayers, 1962; Beeton and Chandler, 1963; Chandler, 1964).

Lake Erie receives the drainage from Lakes Superior, Michigan, and Huron through the Detroit River and discharges into Lake Ontario through the Niagara River and over Niagara Falls. The Lake Erie basin supports a population of 13 million, all but 1.5 million of whom are residents of the United States, more than half of whom are concentrated in the cities of Detroit, Toledo, Cleveland, Erie, and Buffalo. The basin has an annual economy of more than 17 billion dollars.

Although Lake Erie is not the smallest of the lakes in surface area (fig. 1), it contains by far the least volume, one-fourth that of Lake Ontario (the next smallest), due to the extraordinarily shallow depth, 17 m mean and 60 m maximum, compared with 200 to 400 m depths in the other four lakes. A riverine circulation pattern, primarily concentrated along the U.S. shoreline, carries enough water through the lake to replace its total volume every two and one-half years.

Lake Erie is divided into three basins (fig. 2), two of which were heavily silted prior to the Niagara uplift. The western basin, enclosed by a group of islands north of Sandusky, Ohio, has a maximum depth of 11 m and a surface area of 3200 km^2. The central basin, separated from the eastern basin by a ridge between Presque Isle (Erie, Pennsylvania) and Long Point (Ontario), has an overall depth of about 25 m and a surface area of 16,300 km^2. The eastern basin, the youngest portion of the lake, consists of a rounded basin with a maximum depth of 60 m and a surface area of 6200 km^2.

The lake is stratified annually between May and December. By mid-July a stable thermocline exists between 10 and 20 m (near bottom in the western basin) which migrates vertically in response to internal waves and seiches. From late December through March the lake is nearly covered (except in the central basin) by ice accumulated from the shoreline and tributary rivers, often shingled into pressure ridges up to 20 m thick.

Lake-effect storms, contributing heavily to the 800 mm annual precipitation along the U.S. shoreline, characterize the half-year period during which lake temperatures exceed those of the air. During periods when northerly or northwesterly winds carrying few condensation or freezing nuclei in cool dry air masses blow across the lake, tremendous amounts of moisture and energy are contributed by the relatively warmer water. Large drops or ice crystals, borne aloft by thermal circulation in the lake atmosphere, rapidly fall out along the narrow lake plain as the thermal lift is lost. These storms have been the subject of considerable atmospheric research during the past decade. During the storms, the lake surface becomes very rough, not so much as a result of the shallowness of the lake, as commonly claimed (the wave generation is fetch-limited in Lake Erie at storm wind velocities, frequently reaching 30 m/sec, and waves are characteristically of deep-water form beyond a half kilometer from shore), but more likely as a result of wave reflectivity typical of the steep bluff and cliff slopes. Storm surges "set up" by the winds develop seiches in the lake having a node in the vicinity of Cleveland and two-meter or more amplitudes near Toledo and, especially, Buffalo.

Crises on the Lake

As a direct result of the seas and surf developed by storm winds and the variation in lake level (normally ranging about 0.5 m annually) produced by the seiches, shoreline erosion constitutes a significant problem in Lake Erie. Continental rebound accompanying the retreat of glaciation ten thousand years ago (Niagara uplift) has exposed bluffs of poorly consolidated glacial till 10 to 20 meters high around the eastern and central basins of the lake. Erosion has cut back the bluffs at an average rate of 30 cm per year.

The eroded till, together with sediments from agricultural erosion and inadequate control measures around harbors and beaches, amounts to 33 million tons of sediment per year, or over 25 km^3 per century (FWPCA, 1968). Silt is filling the lake at a rate of 3 cm per century in the western basin, 6 cm per century in the central basin, and 16 cm per century in the eastern basin. Extensive long-shore drift carries eroded sediments from the shores of the central basin eastward to depositional sites in the vicinity of Long Point (encroaching upon the deepest part of the lake) and Presque Isle. The geomorphology of the two sites probably differs primarily in that the former has more source material and less coriolis effect than the latter.

Another contributor to siltation and other pollution problems in Lake Erie is the U.S. Army Corps of Engineers' harbor improvement program. Annual dredging of the major harbors of the lake supports a shipping industry which moves 150 million tons of cargo per year, including 20 percent of the world's iron production and 50 percent of the world's nickel production.

The problem of where to dump the spoil is acute. In the lake, the release of sediments reduces water transparency and erodes or clogs the gill structures of aquatic organisms. Entrapped pollutants from the harbor bottoms, especially the nutrients, are released into the lake waters. While the nutrients encourage plant growth, the reduced transparency inhibits photosynthesis. Decreased oxygen production and increased oxygen demand from reduced organic materials in the sediments combine to decrease the dissolved oxygen concentration of the lake water, while gill damage creates additional respiratory problems for the aquatic life. Dumping the spoil in coastal marshes or bays for land-fill buries or destroys the heavily vegetated nursery grounds of many of the lake's animals.

The shipping industry is associated indirectly with oil and gas pollution problems in Lake Erie. Allegedly the first oil and gas deposits in North America were tapped within 100 km of the lake. Currently there are over 500 producing gas wells on the Canadian side. Few are oil producers, and few accidents or spills have occurred to date. However, well-heads are endangered annually by massive ice scour. Such a winter accident, inaccessible beneath the ice, would release quantities of toxic hydrocarbons into the lake waters, leave an artificial asphalt on beaches if oil were released, and possibly send large volumes of brine to the lake bottom where, undiluted, it could destroy all fresh water life. Nearly every community along the shore relies, at least in part, on Lake Erie for municipal water supply, amounting to about 10 percent of the flow rate through the lake. A serious spill rendering the water unpotable might deprive several million people of fresh water.

Spills do occur in tributary harbors and rivers, either from processing plants or shipping and boating. Both the Cuyahoga River in Cleveland and the Buffalo River in Buffalo have proven to be fire hazards due to such spills. On lesser scales, the practice of pumping bilges by ships and small craft and the discharge of up to 30 percent of outboard motor fuel unburned through exhaust and cooling systems, leaves a film of oil on the water surface which reduces gas (including oxygen) exchange across the interface.

Man's activities have resulted in significant physical and chemical changes (Beeton, 1965). Total dissolved solids concentrations have increased by 80 percent (to 180 ppm) while transparency has been reduced by half. Summer dissolved oxygen concentrations in the hypolimnion have decreased to zero in the western basin, less than 10 percent saturation in the central basin, and 50 percent saturation in the eastern basin.

According to Beeton (1965), specific ionic increases since 1900 include calcium from 31 to 38 ppm (120 percent), sodium plus potassium from 6 to 11 ppm (180 percent), chloride from 7 to 24 ppm (350 percent), and sulfate from 13 to 25 ppm (200 percent). Some of the toxic heavy metals, for which no prior concentrations are available, have been reported (Schmidt, 1970) in concentrations as high as 15 ppb for copper, 5 ppb for lead, and 10 ppb for chromium and zinc. Concentrations of arsenic and mercury are nearly undetectable in water, but mercury has been found in concentrations up to 7 ppm in perch and walleye, 10 times the limit considered safe for human consumption. Copper, mercury, lead, and arsenic are used commonly as pesticides, while mercury electrodes (mercury and most of its compounds are generally listed as insoluble in water) are employed in chemical, plastics, and paper manufacture. Lead is scrubbed from the atmosphere (as an automotive exhaust emission) by precipitation, dissolved from "duck shot" pellets used by hunters, and with chromium, zinc, and copper, corroded from trash and solid wastes, dumped into the lake or its tributaries. Heavy metals "fix" or precipitate protein (including enzymes), deactivating the tissue in much the same way as an egg becomes hard boiled.

Other toxic substances introduced into the lake include organic pesticides, in particular those with relatively long half-lives such as DDT and dieldrin (about four years). Seven half-lives are required to decrease the concentration of a substance to 1 percent and 10 are required to decrease its concentration to 0.1 percent. Although DDT has been in use for little over 7 half-lives, and the coho salmon has been an inhabitant of the Great Lakes for a mere 5 years, concentrations of DDT and its residues up to about 20 ppm have been reported for whole fish in Lake Michigan, and 2 to 3 ppm has been found in Lake Erie salmon only 3 years after their introduction. Sale by interstate shipment of food containing 5 ppm of DDT and its residues is prohibited by the Food and Drug Administration. The average concentrations in humans is 12 ppm, an amount equivalent to the mass of one toe, mostly stored in fatty tissue where it is inert. Since DDT is known to affect calcium metabolism, a basic cellular function, one wonders what might happen to a dieting obese person as he remetabolizes the pesticide concentration from storage over a short period of time.

Thermal loading is beginning to create problems on some of the other lakes, for example, southeastern Lake Ontario near Oswego, where two new nuclear power plants are soon to be placed in operation. However, thermal loads have been little burden to Lake Erie so far, perhaps because of the relatively high temperatures attained by the lake water. At Dunkirk, for example, in August the Niagara Mohawk Power Corporation steam generators use water at 20°C as a coolant and discharge an effluent about 10°C warmer (Braun and Jones, 1970). The effluent warms the harbor, creating an artificial thermal bar at the entrance, promoting the growth of some aquatic weeds (but apparently not that of Cladophora, the nuisance alga), and creating frequent fog conditions ("sea smoke") around the harbor. On the other hand, significantly warmed water is not returned to the lake at Dunkirk (the added heat is apparently lost to the atmosphere from the harbor), and the harbor remains ice-free throughout the winter, an advantage enjoyed by boaters, commercial and sports fishermen, fish, and birds. Perhaps, however, our power-hungry society will demand more of the lake's cooling capacity in the near future, possibly strengthening or extending the summer thermal stability of the lake to a greater degree.

The greatest crisis that Lake Erie faces today, however, is eutrophication. A young lake, about 10,000 years old, it has the fertility and other indicators of a lake 60 to 70 thousand years old (Beeton, 1965; Davis, 1964). The nutrient input to the lake, as gauged by phosphates, amounts to over 25,000 tons of phosphorus annually (FWPCA, 1968). The situation for nitrogen, less easily measured, and other nutrients is similar.

The results of eutrophication include enormous growth rates of algae, especially the filamentous green alga Cladophora, algal deposition on beaches where it decomposes creating immeasurable aesthetic problems, oxygen demand as the organic mess returns to the water, and the recycling of nutrients from the decomposed algae to further promote plant growth. This combination of circumstances results in the recently noted oxygen depletion in the hypolimnion, the elimination of many aquatic insects (such as the Mayfly), and the loss of fish species which are dependent upon the insects for food (for example, whitefish and "pike"). The fish which prefer cool water, and thus retreat to the hypolimnion during summer, are frustrated by the insufficiency of oxygen in the deeper water. Competitive "rough fish" take over the lake, feeding on algae until their food supply, oxygen demand, or other needs are no longer satisfied, then die off in large numbers contributing further to problems of oxygen demand and foul beaches.

The nutrients are derived from several sources, the greatest being domestic sewage. Few treatment plants perform any tertiary treatment for nutrient removal. Most plants are incapable of handling the loads they receive, especially those for which interceptors serve as storm drains as well as sanitary sewers. Many lake shore residents discharge raw sewage directly into the lake. Human waste accounts for about 6,000 tons of phosphorus per year, while detergents contribute about 11,000 tons annually to the Lake Erie basin (FWPCA, 1968).

Agricultural runoff, which accounts for about 5,000 tons of phosphorus per year, combines the waste from livestock (cattle produce about 15 times as much organic waste as humans), fertilizers (often applied on snow covered fields, only to run off with the melt water before the nutrients can soak into the soil), and soil minerals eroded from rectangular crop fields crammed onto rounded hillsides. Industrial wastes for an additional 1,000 tons of phosphorus annually, and the contribution of nitrogen from automotive exhausts scrubbed from the atmosphere by precipitation has reached measurable amounts.

The fishing industry, at one time producing nearly 40,000 tons per year commercially and landing about 25,000 tons in 1966 (Applegate and Van Meter, 1970), has felt the brunt of the changes in the lake. According to Smith (1969), a fishery composed of about 60 percent coregonids (cisco, whitefish, and chubs) and about 20 percent salmonids (lake trout) existed around the turn of the century. Commercial landings fluctuated between lows of about 15,000 tons per year (1929 and 1940) and highs around 36,000 tons per year (1915 and 1956) (Applegate and Van Meter, 1970). Species composition has changed until most recently the yellow perch, once considered of only secondary value, constituted over 50 percent of the commercial landings, while sports landings are estimated to exceed those of the industry. Smelt, introduced into the upper Great Lakes early in the century and fished commercially by Canadians since around 1950, have increased to comprise about 30 percent of commercial landings.

The earliest species losses to Lake Erie include the sturgeon, in 1895 a 2,500 ton per year fishery but now a rarity, due to intentional overfishing (sturgeon wrought heavy damage on nets), and the lake trout, a 9,000 ton per year fishery in the 1870's but gone by 1930, due to unintentional overfishing and possibly lamprey predation. The cisco and whitefish disappeared from the lake in 1955 and 1959 respectively, while the sauger and "blue pike" (both pikeperch) disappeared from commercial catches in 1958 and 1960 respectively. The disappearance of these coregonids and percids is related to the loss of insect larvae upon which they feed, the deterioration of summer oxygen supplies in their favored deep cool water, and their failure to breed due to other factors related to eutrophication. The walleye or yellow pikeperch is undergoing a similar decline at present, providing landings of less than 1,000 tons in 1966. Chubs (several species of coregonids) flourished in the last decade, although some species failed to compete successfully with the alewife, but those surviving the lamprey invasion have been lost to interstate markets due to pesticide contamination.

The lost species have been replaced by yellow perch, smelt, alewife, gizzard shad, sheepshead, and the experimentally introduced coho salmon. Except for the perch and smelt, the former fishes are of little commercial or sports value. On the other hand, the coho, which has been known to attain a weight of 7 kg in 2 years, has little prospect of being established as a self-perpetuating species due to its need for clean, cool, flowing "trout streams" for breeding. The streams in Ohio and southern Ontario are predominantly sluggish and turbid. Those in New York and Pennsylvania are either intermittent (driest during the late summer or early fall breeding season) or grossly polluted.

The fishing industry collapsed in 1970 when a graduate student from the University of Western Ontario announced that he had detected mercury concentrations in walleye and perch to levels of 5 ppm. Subsequent investigations indicated the mercury contamination to be a nationwide problem (e.g., 50 times the concentration was reported in Lake Ontario alewives), and it was revealed that the Swedish fisheries on the nearly fresh Baltic Sea had experienced a similar problem 10 years ago. Mercury contamination and DDT residue concentrations in the few remaining useful species have all but closed the commercial fisheries, while the sportsman has been advised to carefully filet the fatty tissue from his catch, to bake, broil, or fry it to remove up to 70 percent of the pesticides, or else neither eat nor feed his catch to pets. Consumer reluctance has reached the "all-you-can-eat" fish fry. The future of commercial and sports fishing in the Great Lakes is indeed bleak.

Recreational losses other than sports fishing have touched many others. Nearly 100 million visits are made annually to 170 shoreline parks. Ten to fifteen percent of the parks had to close their beaches in 1967 due to bacterial contamination. The city of Cleveland has initiated a program of chlorinating its lakefront beaches to render them safe for bathing. Other beaches are fouled by dead fish and decomposing algae, creating an unaesthetic atmosphere for park users. Boaters are reluctant to expose their investments of several thousand dollars to the oil-stained, filthy water. Tybout (1969) estimates that up to $60 million per year may be lost to the Lake Erie recreation industry due to pollution and eutrophication.

Potential for Corrective Action

Any change in the trend of deterioration of Lake Erie depends upon a cessation of pollution. This will require a change in the individual attitudes and efforts of the public. Cleanup cannot be meaningful until the public not only supports State, Federal, and international programs of abatement, but also ceases leaving a trail of debris, litter, discarded beer cans and pop bottles, and raw sewage in the wake of civilization or in the name of progress.

Extensive domestic sewage treatment is necessary. Treatment plants employing advanced waste removal processes will have to be built. Sewer interceptors will have to extend out to the semirural, but populous, areas. Storm drains will have to accompany the sanitary sewers in order to reduce the volume of plant loads during rainy spells. The detergent industry will have to find a substitute for phosphates to produce "whiter, brighter washes." All this demands large contributions from taxpayers and will be noticeable on the supermarket shelves.

Strong enforcement of industrial pollution abatement laws is necessary. Polluting industries will have to be required to cease polluting or shut down. Such an ultimatum now faces some industries in western New York. These requirements, too, will be felt on the supermarket shelves. Society simply must bear the cost of its waste disposal.

Changes in agricultural practices will be necessary. A farmer spreads manure on snow-covered fields because his equipment operates best over the frozen ground, and he need handle the manure only once from barn to crop. New methods of handling, storing, and applying the manure will have to be developed by agricultural engineers. Pest control practices will have to be revised toward decreasing environmental damage. The consumer will feel these increased costs at the supermarket too.

Lake Erie, being the smallest of the Great Lakes by volume, showed the effects of pollution first. Its waters assimilated all the pollutants they could handle, and the symptoms became evident. Having a riverine circulation, the lake should be able to be flushed clean. Provided all pollution ceases entering the lake, it may be estimated that pollutant concentrations might be reduced to about 1 percent in about 18 years (7 flushing periods or half-lives) or about 0.1 percent in about 25 years (10 half-lives). However, lake sediments, acting as reservoirs of pollutants, may continue releasing these to the lake waters for up to 5 times as long, or about 100 years! By this same reasoning, Lake Michigan might require 1,000 years to clean up, should it ever become as polluted as Lake Erie.

Other means of cleaning up Lake Erie must be employed. Since eutrophication is a major part of the problem, nutrient removal by harvest of useful products is suggested. Such removal may not be considered economically profitable, unless the cost of repair to a damaged environment is considered. As undesirable as subsidization may seem, it appears that it might be necessary here. Although somewhat more costly, nutrient-rich spoil from harbor bottoms might better be returned to upland crop lands. Nutrient-rich, fibrous algae might make excellent soil conditioner for these same crop lands. With the elimination of toxicity problems, greater fish harvests might contribute to world protein shortages. This might be facilitated by the careful introduction of useful exotic species, especially predatory fishes. Smith (1969) advises that this is still possible for Lake Erie, since there are other large shallow-water eutrophic lakes in the world from which replacement species may be obtained. He cautions, however, that there are no deep-water lakes from which eutrophic-tolerant species might be obtained if we allow the other Great Lakes to deteriorate as Lake Erie has.

With the application of energy and resources, a technological recovery is entirely possible, and a new life may yet dawn on Lake Erie. The alternative appears to be similar damage to the resources of the remaining Great Lakes, an effectively irreparable loss.

References Cited

Applegate, V. C., and Van Meter, H. D., 1970, A brief history of commercial fishing in Lake Erie: U.S. Dept. of the Interior Fishery Leaflet 630, 28 p.

Ayers, J. C., 1962, Great Lakes waters, their circulation and physical and chemical characteristics: Am. Assoc. Adv. Sci. Pub. 71, p. 71-89.

Beeton, A. M., 1965, Eutrophication of the St. Lawrence Great Lakes: Limnol. Oceanogr., v. 10, no. 2, p. 240-254.

Beeton, A. M., and Chandler, D. C., 1963, The St. Lawrence Great Lakes, Chap. 19, p. 535-558, in Limnology in North America, ed. by David G. Frey: The Univ. of Wisconsin Press, Madison.

Braun, Ruth E., and Jones, J. A., 1970, Thermal loading in Dunkirk Harbor: State Univ. (N.Y.) College at Fredonia, Lake Erie Environ. Studies Tech. Data Rept. 5, p. 1-12.

Chandler, D. C., 1964, The St. Lawrence Great Lakes: Verh. Internat. Ver. Limnol., v. 15, p. 59-75.

Davis, C. C., 1964, Evidence for the eutrophication of Lake Erie from phytoplankton records: Limnol. Oceanogr., v. 9, no. 3, p. 275-283.

Federal Water Pollution Control Administration, 1968, Lake Erie report, a plan for water pollution control: U.S. Dept. of the Interior, 107 p.

Hunt, G. S., 1962, Water pollution and the ecology of some aquatic invertebrates in the lower Detroit River: Proc. Fifth Conf. Great Lakes Research, p. 29-49.

Schmidt, G. W., 1970, Near-shore water chemistry of eastern Lake Erie: State Univ. (N.Y.) College at Fredonia, Lake Erie Environ. Studies Tech. Data Rept. 2, p. 1-34.

Smith, S. H., 1969, Environmental changes in the Great Lakes: Proc. SUNY Conversation in the Disciplines, Lake Erie Environ. Studies, Public Inf. Rept. 1, p. 9-35.

Tybout, R. A., 1969, Economic impact of changes in the water resources of the Great Lakes: Proc. SUNY Conversation in the Disciplines, Lake Erie Environ. Studies, Public Inf. Rept. 1, p. 36-55.

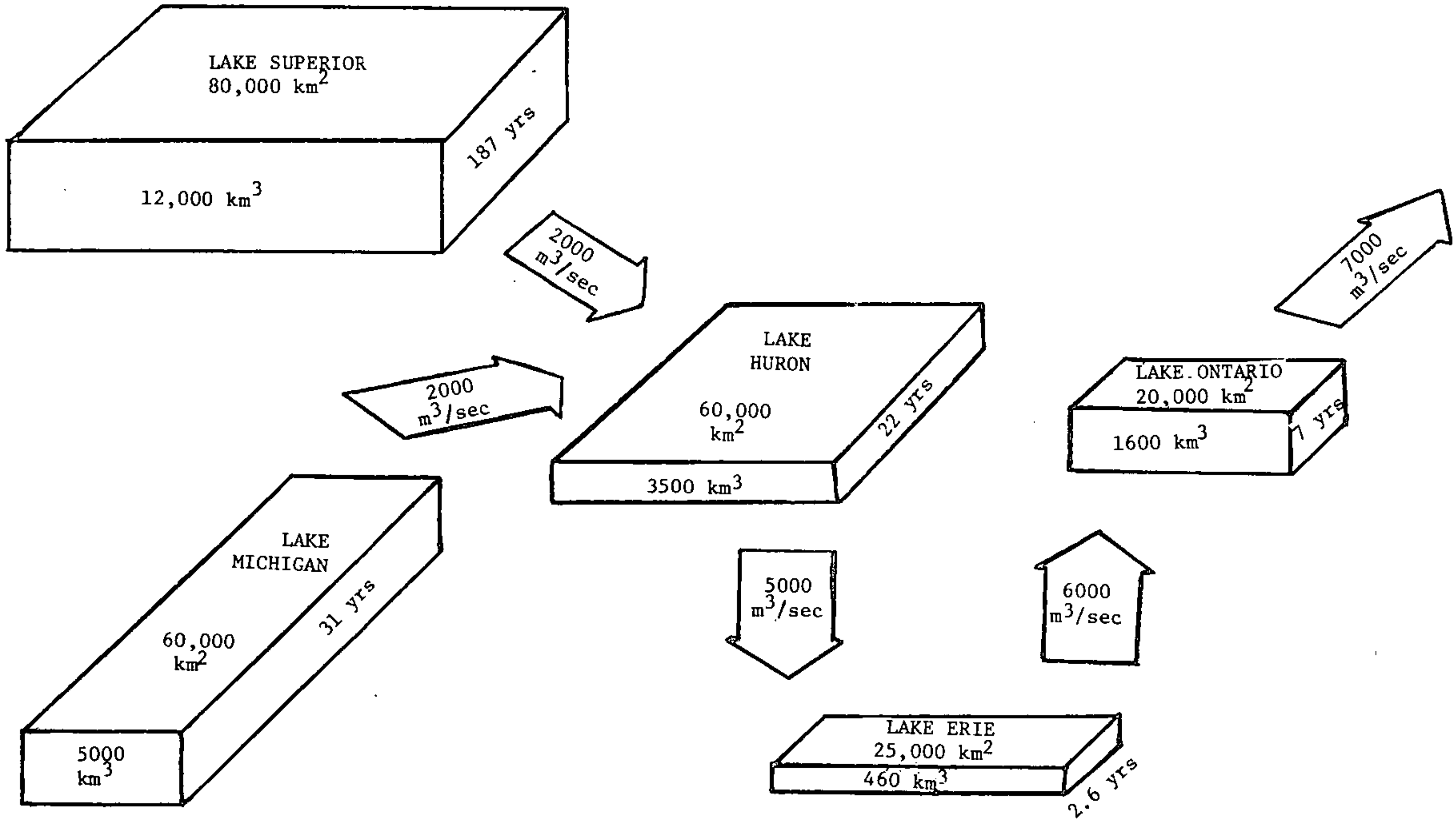


FIGURE 1

HYDROLOGIC RELATIONSHIPS AMONG
THE GREAT LAKES
Indicating surface area, volume, flushing period, and discharge for each lake.

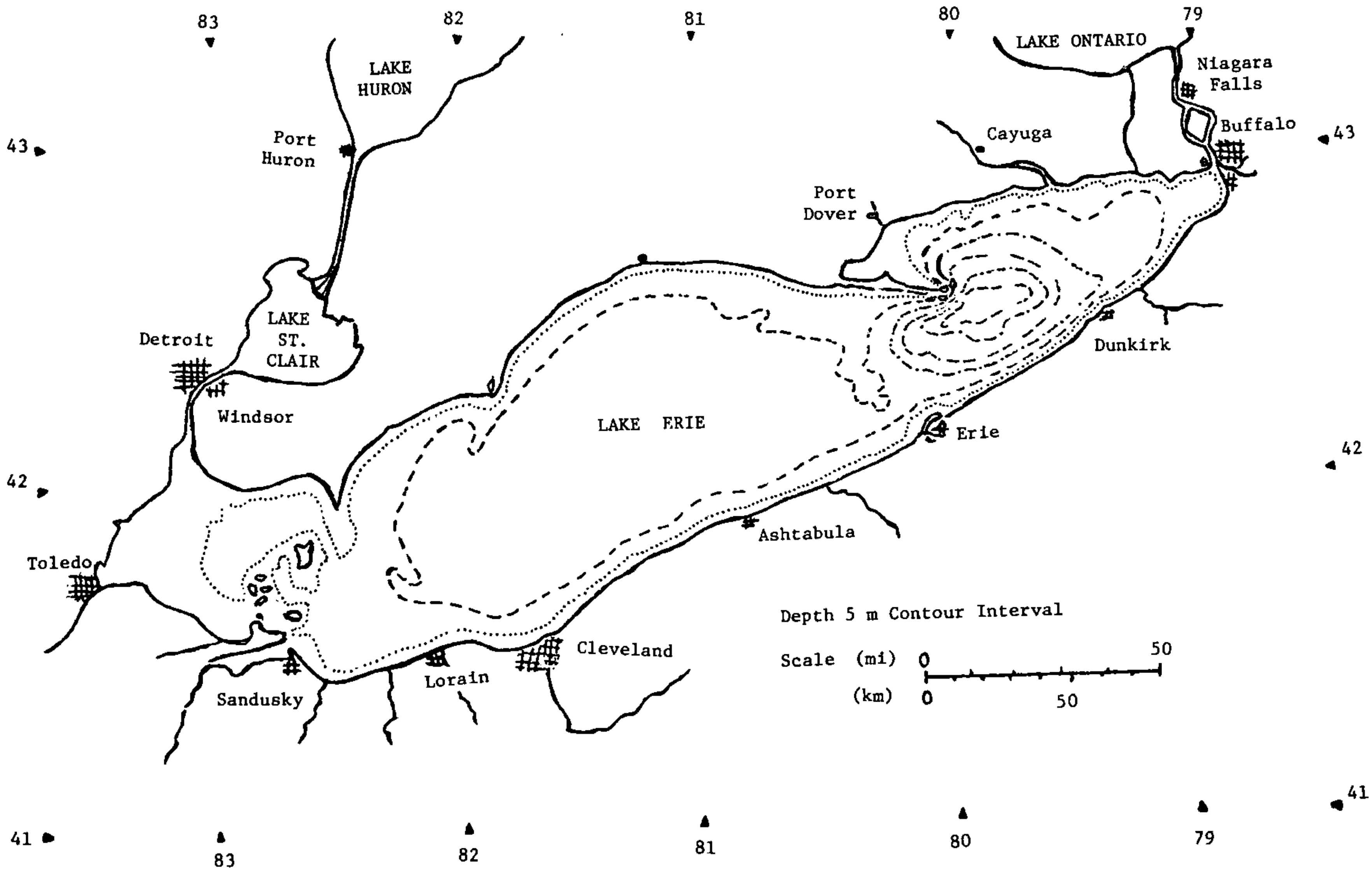


FIGURE 2--LAKE ERIE

URBAN AIR POLLUTION

by

LAWRENCE SLOTE, Eng. Sc.D.

Manager, Environmental Technology, Advanced Civil Systems
Grumman Aerospace Corporation, Bethpage, New York

Introduction

Man's most vital resource is the air he breathes. An average man can live on 4½ pounds of water a day and 4 pounds of food. But to stay alive, he requires approximately 30 pounds of air. He can select his food and water; its contamination is often revealed by taste, odor, or appearance. But he has no choice about the air he breathes. He must take it as it comes to him, even though it may be laden with pollutants.

Air pollution is ubiquitous. It is primarily a problem of municipalities where people and sources of air pollution tend to concentrate. These sources are many and varied. They derive from our expanding needs for transporting ourselves and our goods, and from industrial activities which add copious amounts of gaseous and particulate contaminants to the atmosphere. Expansion of our science and technology brings about new kinds of pollutants which are added to the old. These pollutants derive from combustion of fuels for heat and power, from the processing of materials, and from the disposal of wastes.

All of these trends are increasing rapidly. At the same time, population and urbanization are increasing. In 1920, for example, less than half the country's 100 million people lived in cities. Forty years later, the urban population accounted for 70 percent of the Nation's 179 million people. By the end of the century, 95 percent of an estimated 280 million people in the United States will live in urban areas.

While these and other similar trends of contemporary life continue to rise, one critical factor, the available supply of air, remains constant. The more we concentrate our population into small portions of the total land mass, the less of the total air mass we have available for our use.

Nature and Source of Pollution

The earth's atmosphere is divided into three regions characterized by progressively lower air pressures and widely fluctuating temperatures. The troposphere, which rises to a height of 5 to 12 miles, contains 95 percent of the earth's total air mass and provides the locale for nearly all meteorological phenomena. The stratosphere stretches beyond, to about 60 miles, and finally, the ionosphere, containing mainly charged particles, reaches out to some 650 miles.

Clean, dry air contains 78.09 percent nitrogen by volume, and 20.94 percent oxygen. The remaining 0.97 percent of the gaseous constituents of dry air includes small amounts of carbon dioxide, helium, argon, krypton, and xenon, as well as very small amounts of other inorganic and organic gases whose concentration may differ with time and place. Water vapor and carbon dioxide, which are essentially harmless though present in relatively large amounts, are not generally regarded as part of the pollution problem.

The air also contains aerosols, dispersed solid or liquid particles. The size of the individual species ranges from several angstroms (10^{-8} cm) to hundreds of microns. Suspensions of particles that settle out by virtue of their large size (in excess of 50μ) are customarily classified as particulates, whereas stable suspensions containing smaller particles are referred to as aerosols. Dust particles occur in a size range (0.1-1000μ) that spans the boundary between aerosols and particulates.

Formation of air pollutants can be caused by natural processes or by human activities. Typical of the former are wind erosion, volcanic eruptions, evaporation of sea spray, plant and animal discharges, and atmospheric reactions engendered by solar radiation and lightning. Some 30 million tons of particulates due to natural processes settle out annually over the United States alone.

Human activities contributing to air pollution include mechanized attrition, combustion, and vaporization. Mechanical attrition comprises a large variety of demolishing, crushing, grinding, cutting, mixing, and sweeping operations, a common aspect of metropolitan and industrial activities. The effective extraction of energy from nature by man has significantly contributed to atmospheric pollution. Combustion is utilized primarily to provide energy for motive power, for industrial processes, for electrical power plants, for space heating, and also as a means of refuse disposal.

Emission of the principal pollutants in the atmosphere in the United States totals about 142 million tons per year (table 1).

Table 1.--National air pollutant emissions, millions of tons per year, 1965

	Carbon monoxide	Sulfur oxides	Hydro-carbons	Nitrogen oxides	Particles	Totals	% of totals
Automobiles	66	1	12	6	1	86	60
Industry	2	9	4	2	6	23	17
Electric power plants	1	12	1	3	3	20	14
Space heating	2	3	1	1	1	8	6
Refuse disposal	1	1	1	1	1	5	3
Totals	72	26	19	13	12	142	72

Analysis of table 1 shows: (1) internal-combustion-powered transportation to be the major source of carbon monoxide, the oxides of nitrogen, and the hydrocarbons; (2) central-station generation of electricity to be principally responsible for the oxides of sulfur; and (3) industry to be the principal source of particulate matter.

Though the problem of atmospheric pollution is ubiquitous, it is primarily a problem of municipalities, where pollutants are concentrated and often become entrained in relatively small geographical areas that are also densely populated. For example, the major pollutants found in New York City's air are given in table 2.

Table 2.--Major pollutants in New York City air

Type of pollutant	Tons per year
Carbon monoxide	1,536,000
Sulfur dioxide	750,000
Hydrocarbons	567,000
Nitrogen oxides	298,000
Particulates	230,000

Analysis of table 2 is identical to the analysis of table 1.

The average New Yorker is forced to contend with approximately 870 pounds of pollutants each year. But even this large amount of noxious and obnoxious airborne materials is not enough to cause a major problem, there are other factors which greatly affect a city's air pollution problem, such as location, topography, and climate.

By climate is meant the net result of several interacting variables, including temperature, the amount of water vapor in the air, the speed of the wind, the amount of solar radiation, and the amount of precipitation.

Weather and Air Quality

Air quality is strongly dependent upon weather. When waste products have been discharged into the atmosphere, their subsequent chronological history is a meteorological problem. Even though pollutants are put into the atmosphere at a constant rate, the condition of the weather will determine whether these contaminants accumulate to the point where discomfort and damage result or whether they are thinned out enough so that no problem results. Weather conditions also determine whether such a problem will be localized in one small section of the community or will be widespread.

The weather elements of primary concern in air pollution are: (1) air temperature, (2) instability and turbulence, (3) inversions, and (4) wind direction and speed.

Air temperature

Within the troposphere, the stability of the air can be characterized in terms of its temperature lapse rate, usually shortened to lapse rate. The lapse rate is the rate of decrease of temperature with height. The equilibrium condition for nonsaturated air is $-1^{o}C$ per 100 meters or $-5.4^{o}F$ per 1000 feet. This is the rate at which nonsaturated air would cool if displaced upward, or heat if displaced downward, and is called the adiabatic lapse rate. Thus, if a theoretical parcel of air is moved from a low altitude to a high one and there is no exchange of heat with its environment, it becomes colder at a given rate as the pressure on it decreases and allows it to expand. The reverse is also true: if the air parcel is moved to a lower altitude, the pressure increases, the air is compressed, and its temperature rises.

Instability and turbulence

If the gradient of temperature in the atmosphere exceeds the adiabatic lapse rate, it is obvious that a parcel of air, displaced upward by an infinitesimal amount from a level at which it had the same temperature and pressure as the surrounding atmosphere, will be at a higher temperature than the environment at the new level and will therefore be of lower density than the surrounding air. The force of buoyancy which must result from this condition means that the volume is likely to continue ascending, so that such an atmosphere must be classed as statically unstable. On the other hand, in an atmosphere whose gradient of temperature falls below the adiabatic lapse rate, a mass of air forced upward will be denser than its environment and will tend to sink back to its old level, a necessary condition for static stability. The same result holds if the displacements are downward, and therefore generally, provided that the changes are always adiabatic.

The vertical temperature gradient controls the up and down motions of the air and thus the rate at which diffusion in the vertical direction occurs. For example, in a sunlit level grassland, the warm air near the ground tends to rise, and the cold air aloft to sink, resulting in rapid convective overturning and thorough mixing of the air near the ground with clean air from upper levels. In this way a mixing process, called thermal turbulence is effected and helps to dilute pollutants.

Inversions

Temperature inversion is a meteorological phenomenon which, when occurring over large cities, can have very serious consequences. Essentially, temperature inversion is an atmospheric condition in which the air temperature increases with height above the earth's surface.

Temperature inversions may be brought about in several ways, and occur more often in the fall and during the early morning hours. The most frequent cause of temperature inversions is radiative cooling of the air layer near the surface of the earth. At night, the earth radiates its warmth into space and the ground cools. Air passing over the ground is cooled and sinks. By morning the lowest layers of air are considerably cooler than the air above, thus producing a ground inversion.

A temperature inversion can also be produced by radiative cooling of a cloud bank or a dust layer. In this case, the cool air sinks and is warmed at the adiabatic lapse rate of 5.4^{o}F per 1000 feet. This sinking air will produce a layer of air warmer than the layer of air that is at the earth's surface, thus forming a temperature inversion.

Temperature inversions may also be produced by warm or cold fronts. These frontal inversions are caused by a warm air mass riding over a cold air mass. The reason the warm air rises is the difference in density between warm and cold air.

The final and most efficient inversion producer is a high stationary atmospheric pressure system or anticyclone. Wind currents within the anticyclone spiral slowly downward, in and around the center of the air mass. The subsiding currents, compressed by the weight of the air above, are both warmed and dried, and result in a cloudless sky. The sinking air is compressed further causing the formation of warm air layers over the cooler air mass. The resulting subsidence inversions will then act independently or together with typically formed ground inversions to inhibit the dispersal of air pollutants.

All inversions have one particular feature in common, they are stable. The warm air acts like the lid on a pot, inhibiting the natural upward movement of air; this restricts vertical air currents and air pollutants become trapped in this layer. Unless the inversion is broken, the air pollutants will not be dispersed and an air pollution problem or episode will exist.

Persistent thermal inversions have been experienced in New York City. Under such conditions, lethal layers of sulfur dioxide, carbon monoxide, nitrogen oxides, hydrocarbons, particulates, and many other pollutants have been statically entrapped for days at a time. Either alone or when combined, these pollutants have proved to be detrimental to health, economic welfare, and aesthetics.

Wind speed and direction

Inversions imply a lack of air movement, not just the convection caused vertical movement of air called thermal turbulence. Inversions also imply a lack of wind.

Wind is the horizontal movement of the air from one place to another. It is the means by which contaminants are transported through the atmosphere. The wind speed tells how fast the pollutants are being carried. In addition, the wind speed determines the volume of air into which the pollutant is injected per unit time, and the degree of turbulent diffusion. The stronger the wind, the more energy goes into turbulent fluctuations which spread the pollution laterally and vertically. Wind blowing over level ground ordinarily moves smoothly. Wind blowing over rough and hilly terrain, or around and over tall buildings, stirs up eddies and cross-currents. These swirls are referred to as mechanical turbulence. Thus the pollution tends to be less concentrated if the wind is strong, more concentrated if it is light or calm.

The total accumulated downwind dosage is a function of the variability of wind direction. Naturally, the degree of air pollution you are exposed to depends on whether the wind is blowing pollutants from its source toward you or away from you.

Heat Island Effect

Cities differ from the countryside not only in their temperature, but in all other aspects of climate. The city itself is the cause of these differences. Because of its preponderous high perpendicular buildings and its ravine-like streets and the properties of the materials used in these structures and the surrounding streets, the city absorbs more energy during the day and retains it longer at night. The many vertical surfaces tend to reflect solar radiation to the ground instead of the sky. Since air is heated almost entirely by contact with warmer surfaces rather than by direct radiation, a city provides a highly efficient system for using sunlight to heat large volumes of air. In addition, the city's many structures have a braking effect on the wind, thereby reducing surface wind speed and the amount of heat carried away. The city also produces an appreciable amount of energy generated internally through space heating and other activities. This also contributes to heating the air.

The resulting phenomenon is the heat island effect: warm air tends to concentrate near the structural center of the city. This warm air rises, carrying with it its burden of pollution; then it expands, flows outward over the edges of the city, and, cooling, sinks. Cooler air from the edge of the city flows into the center to replace the rising air and is followed by the now cooled, dirty city air. A self-contained circulatory system has been set up.

Over a long period of time, the continuous introduction and movement of particles creates a dome-shaped layer of haze over the city. In the absence of a prevailing wind, or a heavy rain to clear away the dust dome, this system can become highly stabilized and trap pollutant emissions in a closed system. A characteristic haze or dust dome is created over the city that tends to be self-perpetuating, since it serves to reflect and back-scatter appreciable quantities of solar energy before it reaches the surface.

In winter, since less and less sunshine penetrates the dome to warm the city naturally, more and more fuel is burned to make up the difference. The combustion contributes further to the processes that build up smog. It is in this gradual but inexorable way that the smog problem has attained serious dimensions in many large cities.

Bibliography

American Chemical Society, 1969, Cleaning our environment--the chemical basis for action: Wash., D.C., Am. Chem. Soc.

Bouman, D. J., and Schmidt, F. H., 1961, On the growth of ground concentration of atmospheric pollution in cities during stable atmospheric conditions: Beitr. Phys. Atm., v. 33.

Corman, R., 1969, Air pollution primer: New York, Natl. Tuberculosis and Respiratory Disease Assoc.

DeMarrais, G. A., 1961, Vertical temperature difference observed over an urban area: Am. Meteorol. Soc. Bull., v. 42.

Duckworth, F. S., and Sandberg, J. S., The effect of cities on horizontal and vertical temperature gradients: Am. Meteorol. Soc. Bull., v. 35.

Ferrand, E., 1969, Urbanair: Sci. and Tech., June 1969.

Friedlander, G. D., 1965, Airborne asphyxia--an international problem: IEEE Spectrum, October 1965.

Landsberg, H. E., 1962, City air--better or worse, a symposium on Air over cities: Taft Sanitary Engineering Center, U.S. Public Health Rept. A62-5.

_____ 1963, Air pollution and urban climate: Internat. Biometeorol. Cong. Proc., 3rd, Pau, France, Sept. 1963.

_____ 1966, Dust: Encyclopedia Britannica, v. 7.

Lowry, W. P., 1967, The climate of cities: Sci. Am., Aug. 1967.

McCormick, R. A., and Kurfis, K. R., 1965, Vertical diffusion of aerosols over a city: Royal Meteorol. Soc. Quart. Jour., v. 92.

Mitchell, J. M., Jr., 1953, On the causes of instrumentally observed secular temperature trends: Jour. Meteorology, Aug. 1953.

National Academy of Sciences-National Research Council, 1966, Waste management and control: NAS-NRC Pub. 1400.

New York City, 1966, Freedom to breathe, Report of mayor's task force on air pollution in the City of New York: June 20, 1966.

Pack, D. H., 1966, Air pollution, where and when?: New York Acad. Sci. Annals, v. 136.

Panofsky, H. A., 1969, Air pollution meteorology: Am. Scientist, v. 57.

Sundborg, A., 1950, Local climatological studies of the temperature conditions in an urban area: Tellus, Aug. 1950.

Sutton, O. G., 1953, Micrometeorology: New York, McGraw-Hill.

Tilson, S., 1965, Air pollution: Internat. Sci. and Tech., June 1965.

U.S. Public Health Service, 1966, The sources of air pollution and their control: Public Health Pub. No. 1548.

FINANCING OF WATER SUPPLY AND SEWERAGE PROJECTS

IN DEVELOPING COUNTRIES

by

JUERGEN KROMBACH, C.E.

Senior Sanitary Engineer
Public Utilities Projects Department
International Bank for Reconstruction and Development
Washington, D.C., U.S.A.

As an introduction to the seminar topic "Urban Water Supply and Sewerage Problems in Developing Countries," the objective of this paper 1/ is to explain the World Bank's criteria in selecting and appraising water supply, sewerage, and other environmental sanitation projects. However, before dealing with this specific subject, it appears useful to summarize in the first chapters some recent discussions, and to analyze a few statistics on foreign aid in general and on bilateral and multilateral development financing in particular, as well as to describe the World Bank Group's origin, nature, and functions and the basic criteria, which it applies to the financing of any type of project.

I. BILATERAL AND MULTILATERAL AID

The best known and most comprehensive recent analysis of foreign aid is the "Pearson Report" 2/ which was commissioned and sponsored by, but carried out independently from, the World Bank. Among other statistics, it includes comparisons of the magnitude and regional distribution of financial assistance to developing countries, from developed countries, and from various multilateral institutions during the past decade.

Table 1 shows the total annual average and the regional distribution of "Net Official Assistance" from bilateral and multilateral sources. While these averages refer only to financial assistance under "concessional" terms, cover only a relatively short period of four years (1964-67), and do not include the most recent developments, they reflect the proportions in which "foreign aid" has been allocated, and the relative emphasis which is given by different donor countries and lending agencies to different regions. Attention is drawn to the following:

(i) Multilateral aid represents only 14 percent of the total.

(ii) The U.S. has contributed more than half (53 percent); France, U.K., Germany, Japan, and Canada together have provided more than a quarter (28 percent); and the remaining donor countries (Belgium, Netherlands, Italy, Australia, Sweden, Austria, Denmark, and Switzerland) about 5 percent of the total.

1/ This paper is based on, and has been updated from, the author's presentations in January 1970 at a Water Supply and Sewerage Seminar in Bangkok, Thailand (sponsored by the U.S. Trade Center, Bangkok, and the U.S. Department of Commerce) and at the Second Annual Convention of the Indian Water Supply Association in Bombay, India.

2/ "Partners in Development," Report of the Commission on International Development, Chairman Lester B. Pearson, September 1969.

(iii) The U.S. is the most important donor in all regions, except in Africa, where France has been contributing slightly more.

(iv) Most donor countries have allocated the largest share of their aid to Asia (highest Japan with 98 percent), but a few have given more to Africa, especially Belgium (99 percent) and France (92 percent).

(v) Of the multilateral aid, 43 percent has been for Asia, 32 percent for the Western Hemisphere and 25 percent for Africa. The comparatively high proportion for the Western Hemisphere reflects the important contribution of the Inter-American Development Bank to this region.

With respect to the regional distribution of aid and its allocation to specific countries, the Pearson Report makes some interesting general comments:

> "If aid had been distributed to any economic criteria, the distribution would certainly have been different from what has occurred over the past 15 years...There is also a general bias in aid allocation against large nations, which regularly received smaller amounts of aid on a per capita basis. ...It is absurd, but true, that India would have received more aid in the past if she had split into several independent countries."

Concerning the role of the multilateral agencies the Report states:

> "Since some bilateral donors will continue to give high priority to political, humanitarian and cultural considerations, distribution of additional aid primarily according to performance can be ensured only if multilateral agencies try to fill gaps left by bilateral preferences. This is one of the strongest arguments which developing countries have been making over the past two decades in favor of expansion of multilateral aid. ...The most important advantage of multilateral process is the fact that it is mutual. It gives recipients an opportunity to monitor donors and donors to monitor other donors, as to the performance of their commitments, the quality and terms of proffered aid, the criteria of performance, and the ties and strings attached to aid."

Finally, the Pearson Report expresses some unusual and thought-provoking views on "foreign aid" in general:

"The real economic burden of foreign aid to wealthy nations is often considerably exaggerated. It is not uncommon to hear the total flow of resources to developing countries referred to as something which the rich countries "give" to the poor.

Nothing could be further from the truth, or more misleading. ...The flow of private capital and official credits undertaken for commercial reasons have no more the character of "aid", when they flow to developing countries than when they flow between industrialized countries. ...If there is reason to believe that goods devoted to foreign aid would otherwise have gone to waste, their real cost to the supplier would be nil. ...In view of the fact that most bilateral aid is tied to purchases in the supplying country and helps to promote more production and exports, the real burden must be less than the face value of the resources which are transferred. ...It is doubtful whether transfers directed primarily to military purposes and only secondary to long term development should be thought of as an aid burden at all. In the same vein, suppliers who expect economic returns from general aid programs in terms of a foothold in future markets can hardly maintain that aid is a burden equal to its face amount. In short, the real burden of aid clearly runs below the dollar value of all resources transferred from the developed to the developing countries. This fact deserves to be more widely known."

The Pearson Report does not underestimate the importance of commercial foreign aid programs; what it wants to stress is that foreign aid should be considered under a new light and that the developed and the developing countries should become more aware of their common role: to be "Partners in Development," as is the appropriate title of the Report. In this respect, the multilateral agencies, such as the World Bank, in which both "donors" and "recipients" are represented, are probably the best vehicle to promote this partnership, and to make it operative.

II. MULTILATERAL AID AND THE WORLD BANK GROUP

Table 2 illustrates the amount of lending by the different multilateral agencies for each year from 1960 to 1968. During this period, the number of multilateral agencies increased from 4 to 9. While the World Bank (IBRD) is still the largest among these agencies, its share in the total multilateral operations (which has tripled) has decreased from 70 to 40 percent. The International Development Association (IDA) and the Inter-American Development Bank (IDB), which were founded in 1960 and 1961, respectively, have provided an increasing share of the total, reaching 14 and 15 percent, respectively, in 1968. The share of the UN institution, which have mainly financed project preparation, not implementation, has been fairly uniform with 20 to 25 percent. The new regional development banks, namely the Asian Development Bank (ADB) and the African Development Bank (AfDB) have started operations only in 1968, but are expected to quickly accelerate their lending volume in the coming years.

The World Bank Group (IBRD, IDA, IFC) will probably continue to be the leader among the multilateral agencies. Furthermore, although the volume of multilateral aid will probably always remain small compared with the volume of bilateral aid, the World Bank has an important role as coordinator of multilateral and bilateral aid through the increasing number of consultative groups for specific countries or regions, and through joint financing arrangements. This means that the World Bank has a special responsibility in establishing and applying its criteria for development financing, and it is understandable that these criteria are the target of special interest, and sometimes criticism. But before explaining these criteria, it is necessary to explain briefly what the World Bank Group is and what it does.

III. THE WORLD BANK GROUP--ORIGIN, NATURE AND FUNCTIONS

The World Bank Group consists of three international financial institutions, the World Bank itself, formally the International Bank for Reconstruction and Development (IBRD or, in short, Bank) and two affiliates, the International Development Association (IDA) and the International Finance Corporation (IFC). Each has its own special function, but all are devoted to the same general objective--the promotion of economic development.

The Bank, the senior institution of the three, was established in 1944 together with the International Monetary Fund. It makes loans to governments, or with a government guarantee, at conventional rates of interest. By June 30, 1970, the Bank had 113 members and had lent a total of nearly US$14,300 million 1/ to 87 countries.

The International Development Association (IDA) was created in 1960 and has 105 members (only a few Bank members are not members of IDA). It finances the same general type of projects as the Bank, selected according to the same standards, but on terms which place a lighter burden on the balance of payments of the borrowing country. Its assistance, in the main, has been confined to countries where per capita incomes are exceptionally low (currently, a GNP of US$300 per capita or less determines the eligibility of a country for IDA funds), and which cannot meet all their external capital requirements on the basis of borrowing on conventional terms. At the end of June 1970, credits amounting to about US$2,800 million had been extended by IDA to 55 countries.

1/ A substantial portion of Bank loans (US$2,300 million) has been sold to participating banks, investment companies, etc.

The International Finance Corporation (IFC), founded in 1956, supplements the activities of the Bank by making and encouraging investments on commercial terms in productive private enterprises in developing member countries. By June 30, 1970, IFC had 94 members and has made net commitments totaling US$450 million to private companies in 43 countries. (For the purpose of this paper, the operations of IFC are irrelevant and will not be further mentioned.)

In most major respects the operating policies of the Bank and IDA are identical. Both institutions lend only for projects or programs which are of high priority for the borrowing country's economic development, which are economically and technically sound and which have satisfactory prospects of being carried out and operated successfully. The two institutions apply the same methods and standards in determining for what purposes loans or credits should be extended and in deciding what conditions need to be established to assure that these purposes will be achieved. The interrelationship between the Bank and IDA can be seen from the fact that of the 55 countries which have been receiving IDA funds, 36 have also received Bank loans. Some of these countries received these loans before IDA was established in 1960, and others became eligible from IDA funds as a result of a deterioration in their economic situation after that date; nevertheless, there are quite a few countries which have received and are receiving a "blend" of Bank loans and IDA credits.

Source of Funds

The fundamental differences between the Bank and IDA are in the sources of their funds, which in turn have a bearing on the terms under which these funds are being relent.

The Bank started its operations with a paid-in portion of 10 percent of the subscriptions of its member countries amounting to about US$2,300 million. However, the most important source of its funds has become borrowing in the international capital markets (total outstanding US$4,600 million), mainly the U.S. (outstanding US$2,900 million) and Europe, especially Germany (outstanding US$1,100 million). The Bank's bond issues are secured by the total uncalled capital (90 percent of the members' subscriptions), which is worth US$20,850 million. It is partly because of this large security--and partly because of the Bank's general credit rating as an efficient and profitable organization--that it has been able to borrow, and consequently relend, funds at premium terms. For the borrowing countries, this is the most apparent tangible benefit from the Bank, namely, that it can provide funds at better terms than they would normally be able to obtain by borrowing directly in the capital markets. To illustrate this point, the total amount of bond issues placed by developing countries in the international capital market from 1964 to 1968 has been a significant US$1,800 million, but US$1,400 of this total were placed by 5 out of 26 countries, namely, Argentina, Israel, Mexico, Portugal, Spain. During the same period the Bank placed bonds for US$2,400 million. Nevertheless, because of the increasing cost of the Bank's own borrowings and in spite of its desire to hold its interest rate as low as possible, these rates have increased from less than 4 percent in the first years of Bank operations, to at present 7 1/4 percent.

In contrast IDA credits (the terms "loan" for Bank and "credit" for IDA are normally used to make a distinction between the two operations) are interest free, and carry only a low service charge of currently 3/4 percent. The repayment period is much longer, normally 50 years, compared with 15 to 25 years for Bank loans. These favorable terms are possible only because the major source of funds for IDA credits are grants or interest free loans from 18 nations (the so-called Part 1 countries), of the Bank and IDA members. However, it has been far more difficult for IDA to assure adequate and timely replenishment of its resources than for the Bank to obtain additional funds through borrowing in the capital markets. The original contributions to IDA in 1960 totaled US$780 million; since then they have been twice replenished, in amounts of US$750 million million and US$1,200 million respectively. Also, the Bank has transferred US$385 million from its net earnings to IDA.

Purposes and Regional Distribution of Bank Loans and IDA Credits (Table 3)

In the past, Bank loans have mainly been made for Electric Power (33 percent), Transportation (31 percent) and Industry (15 percent); whereas IDA credits have mainly been for Transportation (31 percent) General Development Programs (24 percent) and Agriculture (23 percent). Water Supply and Sewerage Projects account for only a small fraction (less than 1 percent of Bank loans and less than 2 percent of IDA credits) of the Bank Group's operation; this phenomena is discussed later in this paper.

There are also marked differences in the regional distribution between Bank loans and IDA credits: While the former are more evenly distributed (Asia & Middle East 36 percent, Latin America 39 percent, Europe 18 percent, Africa 14 percent), the bulk of IDA funds (72 percent) went to Asia & Middle East, leaving 20 percent for Africa, 5 percent for Latin America and 3 percent for Europe.

IV. GENERAL CRITERIA FOR PROJECT APPRAISAL BY THE BANK AND IDA

Before any particular project which has been presented to the Bank or IDA for financing, is appraised, the "creditworthiness" of the country is being assessed to ensure, in the interest of not only the Bank/IDA but of the prospective borrowing country; that the terms and amounts of the loan (or credit) are within the limits which the country can reasonably be expected to service, taking into accounts all existing and prospective future foreign debts. The appraisal of the project itself usually involves six different aspects: economic, technical, commercial, financial, institutional, and organizational and managerial aspects.

The objective of the appraisal of the economic aspects is to determine (i) whether the sector involved is of priority for the economic development of the country concerned, and (ii) whether the project is of sufficiently high priority in this sector to justify investment in it. The relative financial return of different projects is frequently not a sufficient test of their relative contribution to a country's development. In many cases, basic investments are required before other investments in more immediately profitable activities can be undertaken.

The benefits properly attributable to these basic investments may be very great even though the direct earnings, at least in the short run, are not high or may even be non-existent.

The economic appraisal involves an investigation of the demand for the goods or services which the project is expected to produce. This study may be of varying scope, ranging from a narrowly localized study, as in the case of a municipal water supply project, to one that is nation-wide, as in the case of a national railway project. In some instances, the investigations may need to be world-wide; for example, in the case of a project to develop a source of iron ore for export. An important question which will normally be investigated during the economic appraisal includes the relative merits of alternative ways to provide the goods and services required.

The appraisal of the technical aspects of a project involves an investigation of the detailed engineering plan for its construction and operation, including the proposed scale of the project, the type of process or equipment to be used, the location, layout and design of the various elements. The technical staff available to the borrower, both for carrying out the project and for operating it, is evaluated and a judgement is reached whether outside help is required. When, in the Bank's opinion, consulting engineers or other experts should be brought in, the Bank often assists the borrower to prepare terms of reference. The choice of consultant is made by the borrower, but the Bank satisfies itself that the consultant chosen is suitably qualified; it believes that a selection should be made on the basis of qualification to perform the work, not on price.

An important part of the technical appraisal of a project is an investigation of the assumptions on which the cost estimates have been calculated. Cost estimates should include adequate contingencies and provisions for interest during construction, and for initial working capital.

The commercial aspects of project appraisal entail a review of all arrangements for buying and selling. In the construction phase, this involves the arrangements for buying the materials needed to construct the project. The Bank is concerned that the borrower shall obtain the best value for the money spent--an objective normally attained by requiring international competitive bidding. For the operating phase, it involves the proposed arrangements for obtaining the raw materials, power and labor needed to operate the project, and for marketing its product.

The appraisal of the financial aspects of a project usually falls into two sections: that concerned with the amount of money required to bring the project into operation and with the sources from which it is to be obtained, and that concerned with operating costs and revenue and prospective liquidity in the operating phase.

Since the Bank and IDA finance only a part of the project cost, it is necessary to ensure that funds from other sources are available on reasonable terms to meet the balance.

Financial projections must also be calculated for the operating period and are necessary, for example, for a revenue-earning project to estimate the financial return on the investment and to determine whether the borrower is likely to have sufficient working capital. In the light of these projections, a judgement has to be made about the soundness of the financing plan.

The institutions are also concerned with the organization proposed for the execution of a project, both during the construction and operating phases. In the case of some projects, the Bank has conditioned its assistance upon the creation of an autonomous operating authority insulated from political pressures and rigidities of government administrative procedures.

The Bank and IDA place particular stress upon the assurance of adequate management for a project. In cases where adequate local management is not available, the borrowing country or the enterprise concerned is asked to look for organizations or individuals qualified to assist in running the enterprise, at least during the initial stages, and to provide appropriate management training to local personnel.

It would seem that all these criteria are reasonable and ought to be applied not only by a lending institution such as the Bank or IDA, but by any authority which is involved in programming, preparing or implementing a project, regardless whether it is located in a developing or in a developed country, and regardless of whether outside financing is involved or not. Yet, as Mr. Shoaib, one of the Bank's Vice Presidents, stated at the 1967 Water for Peace Conference in Washington, "Looking back after two decades, it is easy to see that any country in a position to meet such apparently routine requirements without help could hardly be classified as underdeveloped". However, the conclusion to be reached is not that the requirements are too rigid, but that most of the developing countries need assistance in meeting - gradually - these requirements. This distinguishes the Bank Group (and the other multilateral agencies) from most normal lending institutions: It acts, increasingly, as advisor and counsel for its poorer members and not as a lender who is only interested in protecting his investment.

The key question and the area of potential controversy is, of course, how the Bank and IDA apply their general policies and criteria to specific cases. In the following chapters, this is explained with respect to water supply and sewerage projects.

V. FINANCING OF WATER SUPPLY AND SEWERAGE PROJECTS

A. Background

The World Bank is not a prime lender for water supply and sewerage (henceforth WS&S 1/) projects, nor does it claim to be an authority in financing such projects. Certainly, it is far from becoming what Professor Mehta 2/ once suggested as a desirable vehicle for promoting these projects, namely an "International Water Supply Bank". If any institution deserves such a title, it would be the Inter-American Development Bank (IDB), but its operations are limited to Latin America. Latin America is indeed fortunate to have not only the IDB but also the Pan American Health Organization (PAHO) preparing projects in the sanitary engineering field, and assisting in their implementation. The following table--showing the status as of 1969--may illustrate this fact better than words:

Lending for WS&S Projects	Million US$	% of Worldwide	% of Latin America
Worldwide	895	100	
Latin America	557	62	100
IDB	399	45	72

A comparison between the operations of IDB and the World Bank with respect to WS&S project lending is interesting in several other respects (Table 4). Two points should be highlighted:

(i) Compared with only 1-2 percent of all Bank/IDA lending, IDB loans for WS&S projects represent more than 15 percent of all IDB lending.

(ii) The average Bank/IDA loan for WS&S projects was about US$7-8 million (Bank US$10 million and IDA US$4 million) which is somewhat higher than the average IDB loan for WS&S of US$5 million. However, while the average IDB loan for WS&S has been about the same as the average amount of all IDB loans (US$6 million), the overall averages of Bank loans (US$20 million) and IDA credits (US$13 million) are two to three times higher than the respective averages for WS&S projects.

These comparisons give an indication of the different type and scale of operations of the respective institutions. But WS&S is not the only area of Bank/IDA lending, where the average loan amount is below "normal"; the same is true, for example, in the case of Education Projects.

1/ This refers to water supply or sewerage projects, or a combination of both.

2/ Central Public Health Engineering Research Institute in Nagpur, India.

Also, the number of loans made in the past and their size are by no means an indication of a preference of the Bank Group for specific types and sizes of projects, and there is no "bias" against WS&S projects. The Bank's position and experience with WS&S projects is reflected as follows in the Annual Report - 1970:

"Water supply projects provide valuable benefits to the population of areas in which they are located, but there are often serious problems involved in setting up sound projects for this purpose. The need for such projects is usually greatest in the rapidly growing cities of the developing world; all too often, however, these cities do not charge or collect adequate tariffs, and are dependent on their countries' already overburdened national budgets for urgently needed funds.

This situation, which often leads to the unavailability of sufficient funds to carry out projects, underlines the desirability of adequate levels of charges which will provide the funds to enable the water authority to work effectively.

The Bank Group is also concerned that the water authority has, or can develop, the ability to execute and operate the project in a reasonably effective manner. This often requires a large measure of institution building. The Bank's concern with rate levels and institution building is part of its overall policy of taking every possible step to see that the projects it assists provide a soundly based, economical and self-sustaining service to the community for whose benefit they were established.

Notwithstanding the real difficulties involved in establishing expanding properly managed water supply systems, the Bank hopes it may be able to support further projects during the coming years in this area of urgent need. It encourages and assists in the preparation of suitable projects and examines with special interest UNDP pre-investment studies in this field being carried out by the World Health Organization (WHO)."

Hence, the problem has been mainly that--except in Latin America, which is relatively well assisted by the IDB and others, including the Bank Group--there are not enough suitable WS&S projects ready for financing. In many countries, Water Supply and Sewerage is not even recognized as a matter of national concern. Consequently, the investment programs prepared by the national planning offices of these countries have often no, or only inadequate, provisions for this sector. Usually only the capital cities are able to attract sufficient attention to their needs in water supply and sewerage.

In fact, with a few exceptions, most Bank/IDA lending for WS&S has been for capital cities (see Table 5). There are certain economic arguments for placing a high priority on WS&S projects in large urban areas (there the greatest number of people can benefit from the minimum expenditure of money, manpower, and other resources), compared with smaller cities and rural areas. But the Bank Group is aware that, so far, the projects for which financing has been requested and was provided, were not selected on the basis of balanced and comprehensive country-wide sector studies. This leads to the question of what is the "economic justification" for WS&S projects.

B. Economic Aspects

One of the elements on which the economic appraisal of a WS&S project is based, are demand projections. These should be as detailed as possible and should take into account not only projected population growth, increase in per-capita demand, different requirements and consumption patterns of different consumer groups (domestic, commercial, industrial, public) but also the "elasticity" of water demand, as for example, affected by price, rate structure and metering. Textbooks are not always the best guide in establishing demand estimates, and the per-capita consumption in some developed countries is more an example of water waste than an indication of high economic development. Most important is a realistic estimate of the amount of unaccounted, water, or more general "water losses", which in many cases have been found to be far above any acceptable level, sometimes unknown even to the engineers responsible for the system.

The techniques to analyse projects from an economic point of view, and to quantify the merits of different projects, can only briefly be mentioned here. They are: Cost-Benefit Analysis, Internal (or incremental) Rate of Return Calculation, Discounted Cash flow, Present Worth Analysis, etc. In all these different but interrelated types of analysis, the sources and terms of financing are immaterial. In other words, the results are the same if a project is financed without, with limited, or with a large amount of foreign funds; nor are they affected by the proportion between borrowed funds, funds generated from operations, and others. Economically, all these funds are capital, which has a "price", sometimes called the "opportunity cost of capital". The "price" is different from country to country, but is always above the actual lending rates: nobody would borrow money unless he expects to earn from investing it more than the amount needed to service his debt. Similarly, any country should be careful in investing its scarce financial resources (whether its own or borrowed) in projects which have an economic return below the respective "opportunity cost of capital".

Accordingly, the key factor in analyzing the economic efficiency of any project is the mesurement of cost and benefits in economic, not financial, terms. While the "cost" of WS&S projects can normally be defined without too many difficulties, there is considerable discussion among economists on what should be considered the "benefits". The easiest solution would be to define such benefits as the "maximum consumers would be prepared to pay for succsssive quantities of water or for successively better sewerage service." There are, however, two more types of benefits, normally referred to as "social benefits", which are above those realized by individual customers.

The first is related to the collective nature of water use like--for instance, street cleaning and public gardens watering, in short, the contribution to the aesthetics of urban life; the second - more important - are the "external" effects of water use, namely eradication or reduction of water-borne diseases, resulting in reduced disability, morbidity and death rates, in lower medical expenses and in increased productivity of the labor force. Further benefits are reduced fire losses, and, in turn, sometimes a reduction in fire insurance premiums.

Unfortunately, the efforts spent by many talented people to quantify these "social benefits" have not yet resulted in formulas which have been generally accepted or could be generally applied. Moreover, there is a wide gap between those who consider even a discussion of the desirability to quantify such benefits as "immoral", or at least strange, and those who suggest that (i) from an economic point of view some of these benefits--especially population growth--are no benefits at all, but rather unfavorable side effects of improved water supply; or (ii) "social infrastructure" such as water supply, sewerage, housing is normally productive only in the long run, and cannot be considered a precondition for, but rather a "fruit" from, development; or (iii) improvements in urban WS&S are likely to accelerate migration from the rural areas into the cities and thus worsen the urban problems.

The truth, as always, is probably somewhere between these extreme positions. On the one hand, there are intangible benefits of water supply which cannot be quantified but are important for the improvement of human life and of living conditions. On the other hand, social infrastructure is not a means by itself, but its development should be programmed in balance with other basic investments in the economy. There are quite a few examples, where an originally sound policy of placing priority on productive investments has led to an impasse for further development when there was an overcapacity in, say, electric power and industrial facilities, but a severe backlog in other essential services, such as water supply for industrial and domestic use.

As to the "urban" argument: migration from the rural into the urban areas will take place (and has taken place) even if the social infrastructure is deficient, because urban areas are, and will increasingly become, the essential dynamos for progress in all industrializing countries. The World Bank has become increasingly aware of urban problems and it is concerned about the deteriorating conditions in many cities in the developing world. This was expressed in Mr. McNamara's address to the Bank's Board of Governors at the Annual Meeting in 1969: "The phenomenon of urban decay is a plague creeping over every continent, but its corrosive effects are critical in the poorer nations. The resources required to provide minimal services and infrastructure for urban populations, which in the year 2000 may be 500% higher than today, are staggering. Our knowledge of how to best deal with the whole issue of urbanization remains primitive. But one point is clear: the problem must be dealt with on a comprehensive national basis".

C. Technical Aspects

As pointed out earlier, preparation of WS&S projects for Bank lending has required proportionately much time and effort. In most cases, the reasons were not so much deficiencies in detailed engineering but unsatisfactory planning. This refers mainly to the identification and analysis of alternatives of staging long range master plans, and of alternative schemes for the proposed initial stage, and is closely related to the economic analysis and justification of projects. In many cases, when the Bank/IDA eventually approved a loan, the project had changed substantially from the time when it had first been presented for financing. Changes had been made,

(i) in the scale of the project: and contrary to some beliefs, there have also been cases where the Bank has encouraged much larger schemes than had been proposed;

(ii) in the basic supply alternative: e.g. groundwater instead of surface water and vice versa;

(iii) in the emphasis on various project elements: often the possibilities of reducing water losses by rehabilitating the distribution system had not been sufficiently explored; additional supply would have largely fed water leaks, and would have been lost for actual consumption. This problem is of special importance where supply had been intermittent and supply hours are expected to increase as a result of the project.

Of particular concern in preparing WS&S projects in developing countries are the design criteria. Criteria which have proven to be adequate or may even be standards in "rich" countries with a shortage of labor and with a sophisticated technology should be carefully reviewed and if necessary modified, before being applied to projects under different climatological, social and economic conditions. Important savings in cost can be made if, in preparing specifications for bidding, engineers leave as wide a range of options as possible for different, but equivalent equipment (e.g. pipe materials, pump sizes, meter types). The desire to maintain a reasonable degree of standardization is, of course, an acceptable constraint.

In summary, based on the Bank's past experience, there is much room for improvement in the preparation of WS&S projects. Planning engineers from the developing countries, and consulting engineers from the developed countries assisting them in project preparation, should be aware that the product of their work is in competition with many other proposals for investment in the countries concerned and that it depends, among other things, on the quality of this product whether or not more WS&S projects will be implemented in the future.

Professional enthusiasm alone is not sufficient, and the desire to design a technically perfect scheme, using the most advanced techniques and employing sophisticated devices, often leads into the wrong direction.

D. Commercial Aspects

Under "General Criteria for Project Appraisal" it was stated that these aspects refer to all arrangements for buying and selling, during the construction and during the operating phase.

The "selling" aspect is frequently neglected by agencies responsible for WS&S services; this is understandable, because in most cases the backlog and shortages are so great that it seems hardly possible that there would ever be a problem of finding a market for water. However, there have been cases where it has proven difficult to attract and to connect the projected number of customers to the new facilities. This problem is likely to occur where the project provides new facilities in an area which had previously no or only partial community WS&S service, and where consequently the public was forced and able, and later accustomed, to using private facilities. Special legislation may be needed, but may not be easy to obtain, to ensure an adequate support of the new system.

Naturally, during the stage of project preparation and implementation the "buying" aspect is of much more immediate concern. The Bank/IDA has issued "Procurement Guidelines" which normally become part of its agreements with the borrowers. These Guidelines suggest specific steps to the project authority with respect to preparation of bidding documents, bid advertisement, bid opening, bid analysis, and to general contract provisions. The basic requirement is that--with a few exceptions--borrowers are expected to assure "international competitive bidding" on all contracts related to the project. The term "international" is qualified in the sense that bidding must be open but is limited to all Bank member countries (and Switzerland, which is not a member but has a special relationship with the Bank). In exceptional cases, the Bank may agree to reserve certain contracts for local procurement; however, these contracts may be excluded from the package of works regarded as the "Project" financed under the loan; this has no implications when the loan is only made for foreign exchange expenditures, but it may be important, if the loan amount is determined as a percentage of the total "project" cost.

The requirement of international competitive bidding is accepted by all Bank borrowers without difficulty, when procurement is for goods for which there is no competition from within the borrowing country. There is overwhelming, and sometimes dramatic, evidence from thousands of contracts procured under Bank/IDA financing, that such competition results in substantial savings, compared, for example, with the "tied aid" of many bilateral assistance programs. However, international competition is more controversial when the goods and services involved are also available from within the borrowing country.

The Bank Group's two basic objectives, namely (i) to ensure--through wide competition--that borrowers obtain the best value for their money and that all member countries have the opportunity to participate in such bidding, and (ii) to provide a reasonable degree of protection to the domestic industry of developing countries, thereby stimulating industrialization and economic growth, seem to be difficult to reconcile. In practice, the question is how to compare bids from foreign and local suppliers, and how to determine the "lowest evaluated bidder" to whom the contract should be awarded. In the past, the Bank has, in appropriate cases, and at the request of the borrowers, agreed to a certain degree of "preference" for local suppliers, normally 15%, or the amount of custom duties on the CIF price of the lowest foreign bidder, whatever is lower. Such an across-the-board formula is simple but, depending on each case, it may or may not provide an acceptable and adequate degree of protection for local suppliers. This is especially true if the locally produced goods themselves have a large import component. Therefore, from an economic point of view, a formula based on "value added" (to the import component) would be preferable, but is more difficult to design and more so to apply.

With respect to WS&S projects--as in most other projects--the ability of local firms to compete with foreign suppliers varies from country to country and depends on the stage of development. It is first for civil works, and later in the manufacture of pipes (especially concrete pipes), and then in the production of mechanical equipment (pumps, motors, and sometimes water meters), where local firms become increasingly competitive.

E. Financial Aspects

The need to have sufficient funds available to cover the cost of construction of a proposed project would seem to be a generally accepted fact. It is all the more surprising that in some of the Bank/IDA's WS&S projects, it has taken a long time after the loan/credit was in principle assured, to obtain evidence that the balance of the funds was available from local sources (the project authority, the Government, local financing agencies or others).

However, it is with respect to the financial criteria for the "operating phase," not for "project construction," where the Bank/IDA is most commonly criticized as being too rigid and following a hard line. The principal scapegoat is the concept of the "financial rate of return," or more general "profit," which the Bank applies to all revenue earning projects, and specifically to public utility projects (electric power, telephones, water supply).

The financial Rate of Return (in%) for a given year is defined as:

$$\frac{A + B}{C \times 100}$$

<u>Whereby</u>:

A = Net Income = Gross Income (from Water Sales, Sewerage Service charges, etc.) <u>minus</u> the sum of
- (i) Operating Costs (Salaries, supplies, etc.)
- (ii) Amount added to reserves for depreciation.
- (iii) Financing Charges (see B).

B = Financing Charges = Interest (but <u>not</u> Amortization)

C = Net Fixed Assets = The realistic present value of all fixed assets (excluding inventories and other current assets) except work in progress. <u>minus</u> Accumulated depreciation (based on realistic present value of the fixed assets).

It is important to stress that for the purpose of calculating the Net Income, amortization is not a cost; it is, of course, an expenditure to be taken into account in cash flow forecasts. "Capitalized" Operating Costs (e.g. salaries of staff directly engaged in project preparation and supervision) and Capitalized Interest (interest on loans for projects during the construction period of such projects) have to be deducted from the totals before entering the amounts into the calculation; these capitalized costs become part of the project cost and thus of the "Rate Base."

Arguments brought forward against the "rate of return concept" are both "qualitative" (namely on the principle of using this concept for WS&S projects) and "quantitative" (on the size of the return requested by the Bank). As to the <u>concept</u>, which in simple terms requires a WS&S company to earn enough money to cover not only its current expenditures but to accumulate certain amounts for future expenditures, Barbara Ward, the well-known British economist, who can hardly be accused of being a "capitalist," wrote in 1962:

> "A developing country should aim its policies at ensuring the quickest rate of capital accumulation. Profits should be strongly encouraged, in public as in private enterprise, and tax systems arranged so that all the incentives are towards their reinvestment. This does not always arouse much enthusiasm among planners brought up to believe in the inherent immorality of profits and ready to run essential public services on a 'no profit, no loss' basis. But profits are one of the chief means by which resources can be put at the disposal of society, and, as is little known, are a major source of investment in Soviet Russia."

As to the <u>size</u> of the return, the Bank is aware of the fact that water supply and even more so sewerage authorities, have normally to recover from a substantial backlog in investments and cannot be expected to immediately generate as high returns as would be desirable.

Therefore, as is reflected in most of the Bank/IDA loan agreements for WS&S projects, borrowers are given a certain period of initially low, but increasing returns to achieve the desirable target; the target itself depends on each case, but is normally between 8 to 10 percent. In practical terms, the rate of return concept, coupled with the projections on actual cash requirements (which sometimes demonstrate the need for more funds than would be necessary to achieve the agreed-upon rate of return), has a direct bearing on the charges which have to be levied on the water and sewerage customers. This is where economic and financial "theory" ends, and where practical and often political considerations begin.

It is sometimes argued that it is irrelevant, and the Bank should not be concerned about, how the total amount of the necessary funds for WS&S services is being generated. However, in the Bank's view, the most equitable way of charging for water, and the least conducive to waste, is to relate water charges as closely as possible to actual consumption; this requires metering of preferably all connections which can normally only be achieved in stages. Proposals to charge for water on any other basis than consumption (e.g. property value, fixed amounts with minimum consumption allowance) or to give water "free" to certain consumer groups (hospitals, schools, government) are therefore carefully reviewed during financial appraisal of a WS&S project. It has sometimes been accepted that the Government or the municipality pay, or subsidize payment, for water consumption of certain economically weak consumer groups which they wish to assist.

Financial management of a WS&S company, or of any other public utility, requires an efficient and business-like accounting system. Billing and collection, budget control and budget programming are important areas of financial management. Accounts should regularly be audited by independent auditors. The quality and effectiveness of a public utility company, as of any other business or government, can always best be assessed from the way it is handling its financial affairs.

F. Institutional, Organizational and Managerial Aspects

If there is a single most important objective of the Bank Group's operations, besides providing funds for financing projects and programs, it is to help the developing countries in building institutions which provide the necessary organizational and administrative framework for planning and implementing public and private investments. The need for such assistance is especially great in the WS&S sector. It involves the institutional setup at the national government level, the local organizations responsible for constructing and operating WS&S schemes, and the recruitment of competent managers, experienced professionals and skilled labor to staff such organizations. However, there are no textbooks or formulas which provide a tool for defining the best proposal or for measuring the success in a given case. Neither does the Bank have ready-made solutions.

WS&S has some peculiar features: On one hand, WS&S services are mostly "local," seldom regional, and almost never national (in the sense of nationally interconnected systems).

On the other hand, while the supply of good and sufficient water is essential for almost any economic activity, the demand for industrial, and even less for potable water represents normally but a small percentage of all available water resources in a country; most of these resources are used for other purposes (especially hydropower generation and irrigation). Therefore, one can find a variety of institutional solutions in different countries with respect to the allocation of responsibility for WS&S, and for "water" in general. For the purpose of water resources allocation and from the point of view of WS&S, most of these arrangements can be adequate, as long as it is assured that sufficient quantities of water are reserved for water supply. However, in spite--or possibly because--of the proportionately small quantities of water involved, this requirement is sometimes overlooked and in some national water programs there is "no water left" for community water supply.

More important from an institutional point of view, is the question how to organize and exercise at the national government level regulatory functions related to WS&S services, such as developing and administrating rate policies, monitoring financial performance, setting technical standards, etc. Considering the difficulties of most WS&S services in developing countries, the need for such coordination and central assistance is obvious. Therefore, while the Bank does not necessarily suggest or support the establishment of a national water authority, it strongly recommends instituting and enforcing sound national public utility policies (not limited to WS&S) and giving support to the operating agencies in following such policies.

As to the responsibility for constructing and even more for operating WS&S services, the Bank/IDA's experience indicates that this should normally be left, or delegated, as close as possible to the local level. However, regardless of whether the authority is established at the municipal, regional or national level, it should be organized and operated as a revenue-earning utility, separated from normal government bureaucracy, and not be subject to political interference in its normal affairs. It should be able to independently set water rates in accordance with sound financial criteria and within the limits of generally accepted rate policies in the country. It is in this respect that the Bank/IDA has a preference for setting up a new autonomous authority before approving a loan for a public utility project. Of course, this authority will normally be owned by the public and it may have a board in which the political councils are represented.

Even where such an autonomous authority cannot, or not immediately, be established, the Bank/IDA suggests that the WS&S service be organized as a separate department within the general structure of the respective local or national government. This refers especially to keeping WS&S accounts separate from the general books in order to clearly allocate income and expenditures, and determine the financial performance, of the WS&S service.

The organizational structure of a WS&S service should be functional and should define lines of responsibility in such a way that management can effectively delegate authority without losing control over the operations. This requires the installation of effective management reporting systems and of general communications systems within the organizations.

In this respect, a WS&S service should not be different from any other commercial firm. Experience shows, however, that the principle of operating revenue-earning public enterprises in a business-like manner is least developed at the municipal level and, in turn, seldom adopted for WS&S service.

The best institutional framework and the most perfect organizational structure are useless if there are no men to staff the key positions on the top and at the supporting levels of these organizations. Without any doubt, and this is the case not only in many developing but also in a number of developed countries, WS&S companies are not very glamorous; they have usually great difficulties in attracting qualified staff, and even in competing with other public enterprises in recruiting competent people, especially for the top management positions. In many countries, where career opportunities for engineers in top government positions are scarce, management of WS&S companies is usually "reserved" for civil or public health engineers. While there may be many good reasons for this policy, it fails to recognize that management is an art on its own, and no professional group--engineers, accountants, lawyers, etc.--can claim to offer the best or exclusive qualification for management.

Quality of management and of staff at any level of an organization is always closely related to the salaries and salary incentives, and to the job security which this organization can offer. Public enterprises can seldom compete with salaries in private industry, and thus job security is often their main attraction. Even if this element is absent, as it is for many top positions of politically influenced public services, it is hardly surprising that qualified people stay away from them, and if a Government employee is "deputed" to such an organization, he is more likely to consider it a demotion than a possibility to expand his experience.

In a number of countries, there is not only a scarcity of good managers, but also of engineers with sufficient experience and expertise in the specific technical aspects of a WS&S service. In these cases, scholarships for training in well-established foreign water authorities or for graduate studies at specialized foreign universities may provide a solution, although not for the immediate future. Once a certain amount of experience has been accumulated in the country itself, and this process normally starts at the WS&S services of the larger cities, specialized courses at local universities and national training programs should be established. In this way, experience can be handed down to the smaller cities and to the rural areas. This is a long process, and the absence of sufficient and sufficiently trained staff can be a strong argument in favor of establishing a national water authority responsible for all aspects of WS&S, including operation of certain systems, where the local authorities cannot provide the necessary support of personnel.

The foregoing notes show that the solution of the management problem is first of all a question of manpower and second of education and training. Outside assistance can help to resolve the latter problem, but very little to overcome the first, which will always remain the responsibility of government at all levels in the country concerned. Management consultants can be of great help, and employment of such consultants may be one of the conditions for a Bank/IDA loan. However, they should primarily be advisors to local executives and should be given executive responsibilities only in exceptional circumstances and for a limited period. This does not mean that their task is limited to designing manuals and giving lectures in advanced techniques of business administration; on the contrary, they should not only make sure that the new manuals are understood by the people concerned and can be made operative under the specific circumstances but should--especially in the early phases of their assignment--actively participate, when necessary, in the day-to-day operations of the organization.

VI. LOAN ADMINISTRATION AND PROJECT SUPERVISION

Project selection, preparation and appraisal are only the initial steps in the Bank/IDA's involvement with a specific project. Once a project has been appraised and in principle accepted by the "Loan Committee" in the Bank/IDA, representatives of the respective government, the borrower, and the project authority (which may be identical) are invited for negotiations. After negotiations, the legal documents are finalized and the loan/credit proposal is presented to the Bank/IDA's Board of Executive Directors, who represent the member countries. After the Board's approval, the loan is signed and--provided certain steps are taken by the borrower--becomes effective.

It is at this time, when the second major phase of the Bank/IDA's involvement with a particular project begins: Supervision. On the average, each "active" project is visited at least once a year ("problem" projects more often). The great importance which the Bank/IDA attaches to project supervision can be seen from the fact that there are as many supervision missions every year as there are project identification, preparation, or appraisal missions. In addition, the Bank requests its borrowers to prepare and submit periodic progress reports (monthly, quarterly, annual), covering all important aspects of project construction and of operations. These progress reports are designed not only to provide the Bank with information, but also to serve as part of the borrower's internal management reporting system. Supervision of Bank financed WS&S projects is essentially the same as for any other type of projects. However, as was mentioned in connection with preparation and appraisal, WS&S projects have required much more attention than the "average" Bank project.

VII. OUTLOOK

The Bank/IDA's experience with, and its interest in, Water Supply and Sewerage (WS&S) projects is considerably larger than what the relatively small number of past Bank/IDA lending for such projects would suggest. The number of WS&S projects which are currently under consideration by the Bank/IDA and are expected to result in loans or credits within the next two years is almost twice as large as the total number of WS&S projects financed since the early sixties, when the Bank/IDA started lending in this sector.

This increased emphasis in WS&S projects is in line with the Bank's growing interest in urban rehabilitation and development problems and with the trend of expansion of the Bank's activities into other "difficult" sectors like education and population planning.

TABLE 1

REGIONAL ANNUAL DISTRIBUTION OF NET OFFICIAL ASSISTANCE 1/

FROM BILATERAL (DAC) AND MULTILATERAL AGENCIES

1964-1967 Average

(amounts in million US$ and percentage) 3/

	Africa		Asia		Western Hemisphere		Total		% of Total Bilateral & Multilateral
US	418		2,009	(66)	576		3,003		53
FRANCE	445	(92)	28		15		488		9
UK	198	(50)	175	(44)	23		396		7
GERMANY	94		232	(63)	38		364		6
JAPAN	1		221	(98)	6		228		4
CANADA	14		106	(80)	11		131		2
Others 2/	178	(62)	92		16		286		5
Total Bilateral	1,348	(28)	2,863	(58)	685	(14)	4,896	(100)	86
Total Multilateral	194	(25)	334	(43)	256	(32)	784	(100)	14
Total Bilateral and Multilateral	1,542	(27)	3,197	(56)	941	(17)	5,680		100

Source: "Pearson Report" 1969

1/ Includes only assistance with concessional terms, e.g. IDA but not IBRD

2/ Others:

	Total
Belgium	77
Netherlands	80
Italy	51
Australia	33
Sweden	22
Austria	18
Denmark	6
Switzerland	5
	286

3/ Figures in parenthesis are percentages of country's total official assistance.

JKrombach IBRD
September 1970

TABLE 2

GROSS DISBURSEMENTS BY MULTILATERAL AGENCIES TO LESS-DEVELOPED COUNTRIES, 1960-68

(amounts in million US$)

Agency	1960	1961	1962	1963	1964	1965	1966	1967	1968	%	1960-68	%
World Bank (IBRD)	341	321	409	462	464	474	564	561	605	39	4,201	43
Internatl. Dev. Association (IDA)	-	1	25	105	148	277	273	368	215	14	1,412	16
Internatl. Finance Corporation (IFC)	13	8	18	12	16	19	30	26	31	2	173	2
Sub-Total World Bank Group	354	330	452	579	628	770	867	955	851	55	5,786	61
Inter-American Dev. Bank	-	5	37	75	131	109	142	183	233	15	915	10
Asian Development Bank	-	-	-	-	-	-	-	-	20	1	20	-
African Development Bank	-	-	-	-	-	-	-	-	2	-	2	-
European Eco. Comm-European Dev. Fund	4	17	54	67	85	104	112	105	121	8	669	7
European Eco.Comm-European Invest. Bank	-	-	-	-	6	12	28	39	10	1	95	1
U.N. Institutions	125	197	182	229	263	252	272	207	300	20	2,027	21
Total 1/	483	549	725	950	1113	1247	1421	1489	1537	100	9,514	100

Source: "Pearson Report" 1969.

1/ This total should not be confused with the flow of multilateral "development assistance". These figures include, in addition to official contributions ($661 million), funds raised on private capital markets and repayments on previous loans which are lent at near commercial terms.

2/ For comparison, the following are the gross disbursements of the World Bank Group to all its member countries (Source: Annual Reports IBRD/IDA and IFC, 1970):

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
IBRD	398	485	620	559	606	668	790	772	762	772
IDA	-	12	56	124	222	267	342	319	256	143
IFC	10	12	16	16	16	22	25	33	33	85
Total World Bank Group	408	509	692	699	844	957	1157	1124	1051	1000

JKrombach IBRD
September, 1970.

TABLE 3

IBRD LOANS AND IDA CREDITS BY PURPOSES AND REGIONS

As of June 30, 1970
(amounts in million US$)

	Africa	Asia and Middle East 1/	Europe	Western Hemisphere	IFC	Total IBRD/IDA	Total IBRD	Total IDA	Percentage: Total IBRD/IDA	Percentage: Total IBRD	Percentage: Total IDA
Transportation	1,183	2,310	586	1,173	-	5,251	4,405	846	30.8	30.9	30.5
Electric Power	528	1,194	672	2,411	-	4,805	4,642	163	28.2	32.5	5.9
Industry	254	1,206	590	220	-	2,270	2,166	104	12.3	15.2	3.8
Agriculture, Forestry & Fishing	319	987	157	456	-	1,919	1,294	625	11.3	9.1	22.5
General Development & Program Loans	40	1,067	100	-	-	1,207	552	655	7.1	3.8	23.6
Post-War Reconstruction	-	-	497	-	-	497	497	-	2.9	3.5	-
Telecommunications	38	200	40	101	-	380	244	136	2.2	1.7	4.9
Education	159	82	12	70	-	324	145	179	1.9	1.0	6.5
WATER SYSTEMS	35	74	4	62	-	175	127	48	1.0	.9	1.7
Project Preparation & Technical Assistance	7	11	-	-	-	18	1	17	.1	-	.6
Family Planning	-	-	-	2	-	2	2	-	-	-	-
Financing Loan (IFC)	-	-	-	-	200	200	200	-	1.2	1.4	-
TOTAL IBRD/IDA	2,563	7,132	2,658	4,495	200	17,048	14,278	2,773	100%		
IBRD	2,015	5,143	2,565	4,352	200	14,275	14,275	-		100%	
IDA	548	1,989	93	143	-	2,773	-	2,773	-		100%
PERCENTAGE IBRD/IDA	15.0	41.8	15.6	26.4	1.2	100%					
IBRD	14.1	36.0	18.0	30.5	1.4	100%					
IDA	19.8	71.7	3.3	5.2	-	100%					

Source: World Bank/International Development Association, Annual Report 1970.

1/ Including US$515 million for Australasia (Australia & New Zealand)

JKrombach IBRD
September 1970

TABLE 4

Comparison between the World Bank and the Interamerican Development Bank with respect to Financing of Water Supply and Sewerage Projects
(amounts in million US$)

	All Loans	Loans for Water Supply & Sewerage	% of all Loans
IDB (as of December 1969)			
Number	565	86	15.2
Amount - Total	3,429	457	13.3
- Average	6.1	5.3	
IBRD (Bank) (as of June 1970)			
Number	706	12	1.7
Amount - Total	14,275	125	.9
- Average	20.2	10.4	
IDA (as of June 1970)			
Number	221	10	4.5
Amount - Total	2,773	38 1/	1.4
- Average	12.5	3.8	
Bank and IDA (as of June 1970)			
Number	927	22	2.4
Amount - Total	17,047	163	1.0
- Average	18.4	7.4	

Source: "Annual Report - World Bank 1970" and "Annual Report - IDB, 1969".

1/ Net of cancellations

JKrombach IBRD

September, 1970.

IBRD LOANS AND IDA CREDITS FOR WATER SUPPLY AND SEWERAGE PROJECTS

(As of August 31, 1970)

(amounts in million US$)

						Foreign Financing					
Fiscal Years	Country	Loan or Credit No.	City	WS or S	Total Project Cost	IBRD	IDA	Joint Loans	Total Project Cost	Cancellation and Refunding	% Disbursed
1962	CHINA	9	Taipei	WS	9.7	-	4.4		45	.4	100
	ICELAND	311	Reykjavik (hot)	WS	6.2	2.0	-		32	-	100
	JORDAN	18	Amman	WS	2.9	-	2.0		69	.5	100
					13.8	2.0	6.4			.9	
1963	NICARAGUA	26	Managua	WS	4.8	-	2.0				100
1964	PAKISTAN	61	Dacca	WS&S	50.1	-	26.0		52	12.8	31 2/
	PAKISTAN	42	Chittagong	WS&S	43.0	-	24.0		56	17.0	39 2/
	JORDAN	63	Various Cities	WS	5.0	-	3.5		70	1.0	100
					98.1	-	53.5			30.8	
1965	PHILIPPINES	386	Manila	WS	48.2	20.2	-		42	.6	100
	SINGAPORE	405	I	WS	13.7	6.8	-		50		100
					61.9	27.0	-				
1966	BURUNDI	85	Bujumbura	WS	1.6	-	1.1		69		77
	VENEZUELA	444	Caracas	WS	54.1	21.3	-		39		80
					55.7	21.3	1.1				
1967	PAKISTAN	106	Lahore	WS&S	5.6	-	1.8	1.7 (Sweden)			70
1968	SINGAPORE	503	II	WS	16.0	8.0	-		50		50
	COLOMBIA	536	Bogota	WS	35.3	14.0	-	3.0 (US & Germany)	48		45
	JAMAICA	598	Kingston	WS	9.1	5.0	-	-	55		1
					60.4	27.0	-	3.0			
1969	SINGAPORE	547	III	S	22.4	6.0	-	-	27		19
	MALAYSIA	561	Kuala Lumpur	WS	7.7	3.6	-	-	47		3
	TUNISIA	581	Tunis & Others I	WS	32.8	15.0	-	5.0 (Sweden)	61		3
	CAMEROUN	604	Yaounde Duala	WS	6.7	5.0	-	1.4 (France)	96		36
					69.6	29.6	-	6.4			
1970	GHANA	160	Accra-Tema	WS&S	5.9	-	3.5		59		1
	COLOMBIA	682	Cali	WS&S	37.5	18.5	-	-	49		-
	TUNISIA	209	Tunis & Others II	WS&S	19.2	-	10.5	3.5 (Sweden)	73		-
				-	62.6	18.5	14.5	3.5			
	TOTAL (As of August 31, 1970)	15		WS							
		6		WS&S							
		1		S							
		22			437.5	125.4	69.8	14.6	48		
						(12 Loans)	(10 Credits)				

Source: "Statement of Loans and Credits," as of August 31, 1970.

1/ WS = Water Supply
S = Severage

2/ Of remaining credit after partial cancellation.

JKrombach IBRD
September, 1970

FEDERAL POLLUTION CONTROL LITIGATION

by

WALTER KIECHEL, JR., S.J.D.

Deputy Assistant Attorney General, Land and Natural Resources
Division, U.S. Department of Justice, Washington, D.C.

The year 1970 brings an increasing awareness and concern about conservation of natural resources and improvement of our environment. As a charter member of this seminar, I am aware of the awareness of this group of the problem. In fact, it is due to the activities of scholarly groups such as this seminar, as well as conservation organizations who have long been at work crying the alarm, and local, State, and Federal agencies, and the increasing severity of the conservation and environmental problems that we have this increased concern.

I. Changing attitudes

One of the remarkable things apparent to one who has been engaged in conservation litigation for a number of years is the change in attitudes. I am referring not just to the public concern and awareness regarding conservation values and environmental control. I refer to the change in attitude of responsible officials of corporations, governments, and other such "policymakers."

A case in point is the Great Lakes litigation concluded in June 1967 by decree of the Supreme Court of the United States. To pollute Lake Michigan deliberately is, in this enlightened year of 1970, unthinkable. But it was not always thus. In fact, little more than 10 years ago, the complainants in this litigation, the sovereign States of Wisconsin, Minnesota, Ohio, Pennsylvania, Michigan, and New York, sought and obtained the reopening of the 1930 Supreme Court decree on the representation that the Court should require the return of Chicago's treated sewage effluent to Lake Michigan.

The United States, which had never been a party to this interstate litigation involving diversion of water from the Great Lakes to the Mississippi watershed, intervened. Prominent in the grounds for our motion for intervention in 1959 in the reopened litigation was the protection of Lake Michigan and the other Great Lakes as one of the precious natural resources of the Nation. A comprehensive Federal pollution study of the Great Lakes was initiated; results from that study were introduced into evidence and formed the basis of Findings of Fact confirmed in the decree of the Supreme Court (which, incidentally, became effective March 1, 1970). By this Federal intervention and participation, the proposal for discharge into Lake Michigan of sewage effluent was illuminated and rejected.

Today, the whole endeavor is to keep pollution out of Lake Michigan. Today, there is a considerable amount of anxiety and activity directed toward that end with respect to not only the Great Lakes but our other lakes and rivers. There is great concern also about the pollution of our air, the accumulation of solid wastes, noise pollution, and how we can control these and other such insults to our environment.

II. The "problem"

With this rebirth of responsibility comes the realization that it is not solely a pollution problem. Related is our increasing population, and its concentrations in urban areas; prosperity and greater leisure time; the returnable tourist with the nonreturnable bottle. It is our affluent and expanding society (and you can begin the word effluent with either an "a" or an "e" in this context) that causes many of our environmental problems. As Pogo so wisely observed in this connection: "We have met the enemy, and they is us."

It is unnecessary for me to chronicle the various happenings by which this environment of ours is being despoiled. We are confronted with evidence of that in our daily papers, weekly news magazines, television and radio, and our everyday living. And to those of us who continuously breathe Washington air, and frequently see, feel, or smell the dirty Potomac River, we know, as the song goes, "We got troubles right here in River City."

III. Interrelation of pollution problems

One of the things that needs to be said preliminarily to any intelligent consideration of environmental problems is the complicated and interrelated nature of those problems, factually, legally, governmentally and economically. Moreover, we need to recognize in our consideration of the relationship of our environment to government institutions and legal remedies that the environment is different for each community. Although we have a national problem of water pollution, air pollution, disposal of solid waste, and noise nuisance, some communities may have problems in all of these areas, some in only one or two, and in some rare cases, in none (if you know of any in the last category, please let me know). In some places, the problems are getting worse, and in others, better, and the fragmented treatment of such may lessen one type of pollution and at the same time increase another. An illustration of this is the burning of solid waste because of the increasing shortage of landfill areas; the burning minimizes the landfill shortage but it certainly increases the air pollution. With respect to institutional arrangements (the fancy phrase presently in such vogue), you need to look no further than on the Washington scene to see that these various pollution problems have, up to now at least, been substantially treated as independent and separate problems. Water pollution control is within the jurisdiction of the Federal Water Pollution Control Administration of the Department of the Interior. Air pollution control is under the jurisdiction of the National Air Pollution Control Administration of the Department of Health, Education, and Welfare, Public Health Service, Consumer Protection and Environmental Health Service. Solid wastes or land pollution is within the jurisdiction, as far as what Federal program presently exists, of the Public Health Service, Department of Health, Education, and Welfare. And this lack of coordination is not confined to the executive branch. The jurisdictional overlaps of various congressional committees have contributed to these coordination problems.

This fragmented situation was recognized last year by President Nixon in his establishment of the cabinet-level Environmental Quality Council; and now by the National Environmental Policy Act of 1969, signed by the

President on the first day of 1970. This Act creates in the Executive Office of the President a three-member Council on Environmental Quality. The Council has a legislative mandate to advise and make recommendations on Federal programs and activities and national policies on environment.

IV. Pollution control litigation

The Federal Government first got into the field of water pollution control in a major way by the Federal Water Pollution Control Act of 1948. Starting with the amendments of 1956, adding enforcement powers and other later significant amendments including the Water Quality Act of 1965, the Federal Government has taken an active role. With respect to the intergovernmental relations, the Act states it to be policy of Congress to recognize, preserve, and protect the primary responsibilities and the rights of the States in preventing and controlling water pollution and disclaims any effect on the rights of such States. Moreover, the specific policy enunciated in connection with the enforcement provisions is that State and interstate action to abate water pollution is encouraged, not displaced, by Federal enforcement action. However, subsection (a) of Section 1 of the Act says that the purpose of the Act is "to enhance the quality and value of our water resources and to establish a national policy for the prevention, control and abatement of water pollution."

How does the Act undertake to accomplish this purpose? It provides for research not only by the Federal Government itself but by Federal grants; it encourages interstate cooperation and uniform laws; it provides for Federal grants for construction of sewage treatment works and grants for research and development as well as water pollution control programs by the States. And it provides for enforcement measures against pollution of interstate or navigable waters. These provisions were substantially added to by the Water Quality Act of 1965. In connection with water quality standards, the law provides in general for the States to adopt water quality criteria applicable to interstate waters or portions thereof within such State, and a plan to enforce the same; and if the Secretary of the Interior determines that such criteria and plan protect the public health or welfare, enhance the quality of water and serve the purposes of the Act, then such criteria and plan shall be the water quality standards applicable to such interstate waters. The Act authorizes the Secretary to establish standards, in the event of the failure of a State to act. All States have acted in this matter and the water quality standards are being established, state-by-state. Discharge of matter into interstate waters, which reduces the quality of such waters below the water quality standards established, is subject to abatement under the enforcement provisions.

The history of the Clean Air Act is similar, although a few years later in point of time. The Act of 1955 provided for research and technical assistance by the Federal Government. The amendments of 1963 added enforcement powers and the Air Quality Act of 1967 provided for establishment of air quality standards, as well as an "emergency" enforcement provision, both authorizing enforcement without resort to the three-phase procedure.

Generally speaking, the three-phase procedure may arise in one of two ways:

(1) Proceeding to abate the pollution of air or water which is interstate in character or of navigable (including coastal) waters may be initiated by the Secretary of the Interior with respect to water pollution, and the Secretary of Health, Education, and Welfare with respect to air pollution, acting on his own or upon the request of a Governor or of a State pollution control agency of an affected State (or in certain circumstances, of an affected municipality).

(2) Proceeding to abate pollution which is intrastate in character (that is, pollution endangering the health or welfare of persons only in the State in which the discharge originates) may be initiated by the appropriate Secretary, whenever requested by the Governor of that State.

In either case, the first formal act in any enforcement proceeding is the calling by the appropriate Secretary of a conference of State and interstate pollution control agencies. The agencies may bring such persons as they desire to the conference. The statute requires that interested parties (i.e., polluters) be given an opportunity to present their views to the conference. The conference goes into detail as to the nature and effect of the pollution and considers means of abatement. Following the conference, the Secretary recommends remedial action to the appropriate agencies and allows such agencies at least 6 months for the taking of such action.

Thereafter, if remedial action satisfactory to the Secretary has not been taken, he calls a public hearing before a five-man hearing board which he appoints. The board makes findings as to whether the pollution is occurring and whether effective progress toward abatement is being made. If progress is not being made, the board makes recommendations concerning the measures that should be taken to secure abatement. The Secretary sends the findings and recommendations to the alleged polluters together with a notice specifying a reasonable time, not less than 6 months, in which the pollution is to be abated. He also sends the findings and recommendations to the State and interstate agencies involved.

If the pollution continues after the specified time, the Secretary (in case of interstate pollution) may request the Attorney General to bring suit on behalf of the United States to abate the pollution. In the case of intrastate pollution, the Secretary may do so only with the consent of the Governor of the State in which the pollution originates.

The court must receive in evidence in any suit for abatement the transcript of the proceedings before the hearing board and a copy of the board's recommendations. The court may receive further evidence in its discretion and, giving due consideration to the practicability and to the physical and economic feasibility of securing abatement of any pollution proved, has jurisdiction to enter such judgment as the public interest and the equities of the case may require.

There have been and are a number of enforcement conferences initiated under the Water Act. Substantial progress, measured either in terms of improvement of water quality or amounts of money spent for pollution abatement, has been achieved by these proceedings. In only one case to date has court action been required.

In 1960, the Department of Justice brought under the Federal Water Pollution Control Act an action entitled United States v. City of St. Joseph, Missouri, in the Western District of Missouri. There, the city of St. Joseph, Missouri, was polluting the Missouri River with untreated sewage. It refused to take remedial action on the grounds that its citizens had refused to vote a bond issue to provide a sewage plant and, accordingly, the city was without power to act. After pretrial hearings, the city, under threat of severe judicial penalties, took steps to build a sewage plant. To insure this action, the court entered an order dated October 31, 1961, requiring the city to file periodic progress reports with it, which the city has done.

Manifestly, the three-phase procedure is quite ponderous and lengthy with the various statutorily prescribed minimum periods. In the St. Joseph case, for example, the interstate conference was in June 1957, the hearing in July 1959, and the court complaint filed in September 1960. Moreover, had it been necessary to go to trial, the court review would not have been limited to the hearing board's findings and recommendations to determine whether they are supported by substantial evidence. Instead, the court is, under the statute, free to weigh all such evidence as well as what further evidence is permitted at trial, and make independent findings and determinations.

The additional enforcement procedure authorized by the Water Quality Act of 1965 amendments is designed to permit more expeditious enforcement. The discharge of matter in violation of such standards is subject to abatement in court action after 180 days notice by the Secretary to the violators and other interested parties. However, the court in an action based upon violation of the standards may undertake a complete review of the standards and the practicability and feasibility of complying with such.

Under the Clean Air Act, a number of enforcement conferences have commenced. Only one of these has gone beyond the conference recommendation stage. That case involves a rendering plant in Bishop, Maryland, which was charged with emitting vile odors endangering the health and welfare of persons in Delaware.

In the first suit brought under the Clean Air Act, 42 U.S.C. 1957 et seq., the Fourth Circuit Court of Appeals has upheld the injunction issued by the district court against the Bishop Processing Company. Speaking for the court, Judge Sobeloff affirmed the order of the United States District Court for the District of Maryland, which directed the processing company to cease all manufacturing and processing in its rendering plant.

The Bishop plant began operating in 1955 in Bishop, Maryland. From 1959 to 1965, the States of Maryland and Delaware engaged in futile efforts to abate the malodorous air pollution which moved across the State line, polluting the air of Selbyville, Delaware. In 1965, the Secretary of Health, Education, and Welfare was requested by the Delaware authorities to take the necessary action to secure abatement of the air pollution problem. After several years of administrative proceedings under the Clean Air Act failed to produce abatement of the noxious odors emanating from the plant, suit was brought against Bishop.

In November 1968, Bishop stipulated to the entry of a consent decree, agreeing to "cease all manufacturing and processing" upon the filing of an affidavit by Delaware government officials "stating that the defendant is discharging malodorous air pollution reaching the State of Delaware...." Under those terms, the United States twice filed affidavits with supporting documents alleging continued interstate pollution. The second filing resulted in the entry of an injunction closing down the plant. The Fourth Circuit Court determined on March 3, 1970, that the lower court's action was correct in all respects; since it had been shown that the pollution continued in violation of the decree, Bishop was properly ordered to shut down its operations.

Looking to the future, the Clean Air Act as amended in 1967 also provides for direct enforcement of air quality standards, once such standards are established. The procedure for setting of air quality standards is sufficiently new and different than the procedure for setting water quality standards that some detail is in order. Like the standard-setting procedure for water quality standards, the initial formulation of standards is a matter of State action. Before State action, however, the Secretary of Health, Education, and Welfare is required to take the three following actions:

(1) Designate air quality control regions, based on a number of factors necessary to provide adequate implementation of air quality standards.

(2) Develop and issue criteria of air quality requisite for the protection of the public health and welfare.

(3) Issue information on those recommended pollution control techniques necessary to achieve levels of air quality set forth in the criteria.

Within 90 days after receiving any air quality criteria and recommended control techniques, the Governor of a State may file a letter of intent that such State will, within 180 days, adopt, after public hearings, air quality standards for any designated air quality control region or portions thereof within its jurisdiction, and will, within 180 days thereafter adopt a plan for the implementation, maintenance, and enforcement of such air quality standards.

If the Secretary determines that the standards and plan are consistent with the Act, and provide adequate enforcement authority, including authority to deal promptly with emergency air pollution conditions, such standards and plan become the air quality standards applicable to that State.

If the State does not take the prescribed action, or if the Secretary finds the standards and plan are not consistent with the Act, he may, after reasonable notice and a conference of representatives of "appropriate Federal departments and agencies, interstate agencies, States, municipalities, and industries involved," publish standards for air quality regions within that State. Unless, within 6 months from such publication, the State has adopted its own consistent standards or has asked for a public hearing, the Secretary is directed to promulgate such standards.

Prior to 30 days after the promulgation date of Federal standards, the Governor of any affected State may ask for a public hearing. The hearing board, on the basis of the evidence presented to it, may approve the standards or modify them and such action is binding on the Secretary.

The statute contemplates that the standards, established by either of the routes outlined above, will be implemented by the State concerned, since further Federal action is contingent on findings by the Secretary that: (1) the air quality in the region is below the standards, and (2) that such lowered air quality is due to the failure of a State to take reasonable action to enforce such standards.

If these findings are made, the Secretary is directed to notify the affected State or States, persons contributing to the alleged violation, and other interested parties of the violation. Unless reasonable action to enforce the standards is taken within 180 days from such notification, the Secretary may, in the case of pollution "which is endangering the health or welfare of persons in a State other than that in which the discharge or discharges (causing or contributing to such pollution) originate," ask the Attorney General to bring suit on behalf of the United States to abate pollution.

If only intrastate pollution is involved, the Secretary is not authorized to take action on his own initiative but may, if so requested by the Governor, provide technical and other assistance to help the State abate the pollution or ask the Attorney General to bring suit on behalf of the United States to abate the pollution.

If suit is brought under these provisions, the court will receive in evidence the record and recommendations of the hearing board convened on standards, and "such additional evidence, including that relating to the alleged violation of the standards, as it deems necessary to complete review of the standards and to determination of all other issues relating to the alleged violation." After giving due consideration to the practicability and to the technological and economic feasibility of complying with the standards, the court may "enter such judgment and orders enforcing such judgment as the public interest and the equities of the case may require."

And in addition, the Air Quality Act of 1967 added a third judicial remedy or Federal enforcement procedure. Pursuant to the so-called emergency provision, the Secretary, upon receipt of evidence that pollution is presenting "imminent and substantial endangerment to the health of persons" and finding that State or local authorities have not acted to abate such pollution, may request the Attorney General to bring suit.

In addition to the Water Pollution Control Act and the Clean Air Act, the Federal Government may bring pollution suits under the Refuse Act. It was enacted in 1899 as a criminal statute but has been interpreted to permit injunctive suits. It prohibits the depositing of refuse into any navigable waters of the United States. The Refuse Act is one of the legal bases of the test case on thermal pollution--the pending suit against Florida Power and Light Company with respect to Biscayne Bay.

Conclusion

Decisions of these cases involve consideration of socioeconomic, technical, and "public interest" questions as well as strictly legal questions. Indeed, the two comprehensive Federal acts to which I refer, the Water Pollution Control Act and the Clean Air Act, expressly provide that in enforcement suits brought pursuant to these Acts, the court, "giving due consideration to the practicability and to the physical and economic feasibility of securing abatement of any pollution proved," has jurisdiction to enter such judgment "as the public interest and the equities of the case may require." So the recalcitrant polluter can drag his feet through the enforcement proceedings, administrative and judicial, over a number of years, never denying the fact of his pollution, but arguing to the end that it is neither in the public interest nor equitable to close him down and throw his employees out of work. I am not speaking entirely hypothetically; the described state of affairs has a remarkable resemblance to the situation in the Bishop case. And notwithstanding the public awareness about pollution and the resurgence of responsibility, public and private, for its abatement, to which I have referred, we all know that the defendant in the Clean Air case is not the only recalcitrant polluter alive and polluting grossly in the United States.

So, in conclusion, I say to you, the challenge to us is to seize the opportunity presented by the present climate of opinion. Recognizing the complexity of these matters, and recognizing that marked improvement in our environment won't come easily or quickly, the time to make real progress is now. We in the Department of Justice are prepared to do just that. We expect to file and win new pollution abatement suits. We will use all effective legal remedies available to us. We are in the forefront of the fight for a better environment.

DETERMINATION OF QUALITY OF SEDIMENT ON THE

PUBLIC BEACHES OF LONG ISLAND

by

YESHAWANT K. PURANDARE, M.S. in Chemistry

Associate Professor of Chemistry, State University of
New York at Farmingdale

Introduction

With the advent of scientific knowledge and technology, man has inadvertently and carelessly contaminated his environment. Increased industrial production has resulted in letting undesirable pollutants mix with our air, drinking water, and food. Recent discoveries of mercury in rivers has caused the U.S. Government to apply stringent regulations and strict enforcement of these laws. In order to protect his food supply, man has been waging war against insects, weeds, bacteria, etc., for a number of years. Indeed, pesticide residues are found today in virtually every part of this planet.

Due to population increase and shortage of food, ocean floors in the near future will have to assume the role of land for growing food. Oceans will also become vast areas for mining. Today, ocean waters are increasingly used as recreational playgrounds. It is now imperative that human beings carry out intensive investigation into the character of ocean waters and ocean floors.

There are several public beaches, boating facilities, and other recreational areas along the shores of Long Island. It will be interesting and of value to inquire into the quality of the sediment at these public beaches, and if found unsatisfactory, a healthy discussion regarding the ways to better the sediment quality can follow.

In the present work it is proposed to carry out quantitative estimation of mercury, hexavalent chromium, and residues of commonly used chlorinated pesticides.

Methods of Analysis:

Mercury: Two methods for concentrating mercury are available. One consists of coprecipitation with copper as sulfide[1], and the other extraction with dithizone.[2,3] Sandell[4] has described a colorimetric method for estimation of mercury in dithizone solution. This method has been used even in clinical applications, such as estimation of mercury in urine of patients.[5] Atomic absorption spectroscopy, being more selective and highly sensitive,[6] has become a major tool for detection and quantitation of several elements including mercury.[7-10]

Hexavalent Chromium: Hexavalent chromium (Cr^{+6}) is of particular interest due to its carcinogenic potential. Titrimetric,[11,12] gravimetric,[13,14] colorimetric,[4,15-20] and atomic absorption[21] methods are available for the estimation of chromium. Due to the complexity of interferences by other metals such as iron, molybdenum, mercury, etc., in other methods, the atomic absorption method has become a method of choice.

Residues of chlorinated pesticides: Literature on the methods of analysis of pesticide residues is most abundant. In this country, most of the work in this field is published in five journals--J. Ass. Off. Anal. Chem., J. Agr. Food Chem., Bull. Environ. Contam. Toxicology, J. Chromatography and Analytical Chem. Methods range from gas chromatography, thin-layer chromatography, column chromatography, mass spectrometry, nuclear and quadruple magnetic resonance, countercurrent distribution, to isotopic dilution.

Experimental:

I. Colorimetric Estimation of Mercury:[4,5]

A sample of beach sediment is mixed with 30% sulfuric acid solution and excess potassium permanganate. The mixture is then refluxed for one hour to oxidize all organic matter and to bring any mercury in organic compounds to ionic form. After excess of potassium permanganate is destroyed with hydroxylamine, the pH of the solution is adjusted between 1.0 and 2.0; and mercuric ion (Hg^{+2}) is extracted with dithizone solution in chloroform. Optical density of this extract is measured at 620 mu. Mercuric ion is back extracted with potassium acid pthalate and potassium iodide solution, and the optical density of the dithizone layer is again measured. The difference between the two optical density readings is proportional to the concentration of mercuric ion. This procedure eliminates interference due to silver and copper ions.

Preliminary studies on the beach sediment obtained from the public swimming area at Hecksher State Park have shown approximately 1.5 ug. of mercury per 100 gms. of dry sediment. Mercury determination on the same sample by atomic absorption spectroscopic method was found to be about 1.1 ug. mercury per 100 gms. of dry sediment.

II. Atomic Absorption Method for Estimation of Mercury:[7-9]

Mercuric ion is extracted with dithizone and back extracted with potassium hydrogen pthalate and potassium iodide as described above. Mercuric ion is then reduced to free mercury by addition of a solution of stannous chloride. Air is bubbled through this solution to vaporize free mercury, which is collected in a glass cell. Radiation signal from a mercury vapor lamp (λ=2536 Å) is passed through the cell, and the intensity of absorption is recorded, the latter being proportional to the concentration of mercury present. Alternate treatment of the extract consists of aspirating a solution containing mercuric ion into a flame and measuring the loss of intensity of same radiation signal while passing through the flame.

Dr. Rowley of Brookhaven National Laboratories kindly granted me permission to work in his laboratory to perform atomic absorption analyses. He also supervised my work done in his lab. One sample spectrum of atomic absorption is on page 6.

III. Colorimetric Estimation of Hexavalent Chromium:[4,15]

Hexavalent chromium is extracted from highly acid solution with diphenyl carbazide to produce reddish purple color which is measurable at 540 mu.

IV. Analysis of Chlorinated Hydrocarbon Pesticide Residues:[21-22]

A sample of beach sediment is extracted with pesticide-free chloroform. The neutral constituents of the extract are separated by acid and basic extractions followed by adsorption on silica-gel column. The components of the neutral fraction are identified by comparing their R_f values with those of standards in thin-layer chromatography.

It is proposed to analyze beach sediments for following most commonly used chlorinated hydrocarbon pesticides: Methyl parathion, Parathion, Dieldrin, Endrin, Heptachlor, Heptachor-epoxide, Lindane, DDD, DDT, DDE, Aldrin, and γ-Chlordane.

References

1. Stock, A., Cucuel, F., Naturwissenschaften 22, 390 (1934)
2. Hamaguchi, H., Kuroda, R., Hosora, K., J. Chem. Soc. Japan 82, 374 (1961)
3. Gray, D. J. S., Analyst 77, 136 (1952)
4. Sandell, E. B., "Colorimetric determination of traces of metals," Interscience, N. Y., p. 621-639 (1965)
5. Brays' Clinical Laboratory Methods, 7th Edi., Mosby, St. Louis, p. 694 (1968)
6. "Advances in Chemistry Series," No. 73, "Trace Inorganics in Water," American Chem. Soc. (1968)
7. Chau, Y. K., Saitoh, H., Environ. Sc. & Tech., 4, No. 10 (Oct.), p. 839-41 (1970)
8. Kahn, H. L, et al, Atomic Absorption Newsletter, 7, No. 2, p. 35 (1968)
9. Hatch, W. R., Ott, W. L., Ana. Chem., 40, 2085 (1968)
10. Lindstrom, O., Ana. Chem., 31, 461 (1959)
11. Bourret, P., Lecuire, J. M., Chim. Anal. (Paris), 50, 163-6, (1968)

12. Iritani, N., et al, Bunseki Kagaku, 17, 1075-80 (1968)

13. Kitano, M., et al, Nippon Kagaku Zasshi, 90, 190-93 (1969)

14. Varughese, K., Vaida, V., Anal. Chim. Acta, 50, 176-9 (1970)

15. Standard Methods for the Examination of Waste and Wastewater, Am. Public Health Assn., N. Y., 12th Edi. p. 478 (1967)

16. Rowland, G. P., Anal. Chem., 11, 442 (1939)

17. Saltzmann, B. E., ibid, 24, 1016 (1952)

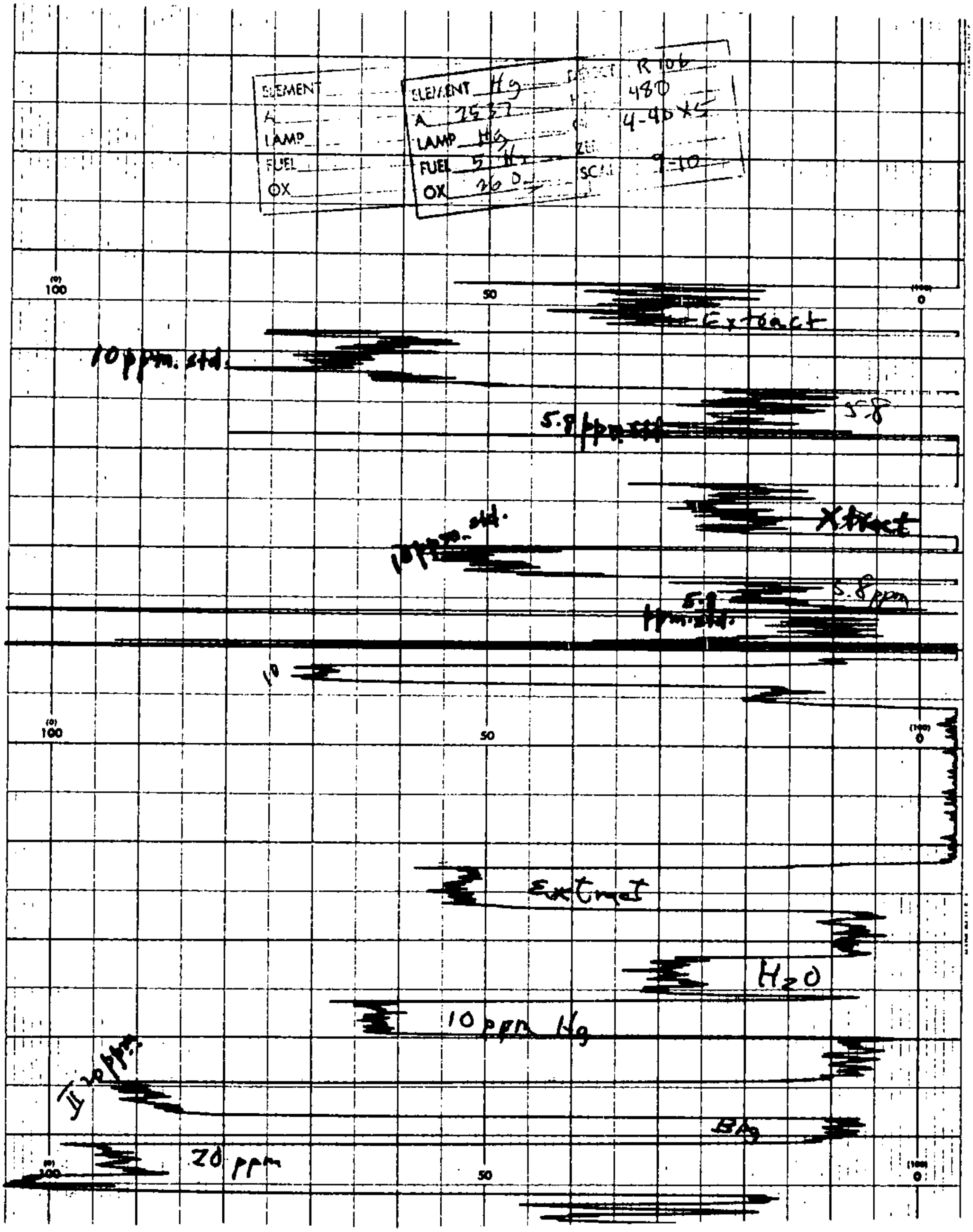
18. Urone, P. F., ibid, 27, 1354 (1955)

19. Allen, T. L., ibid, 30, 447 (1958)

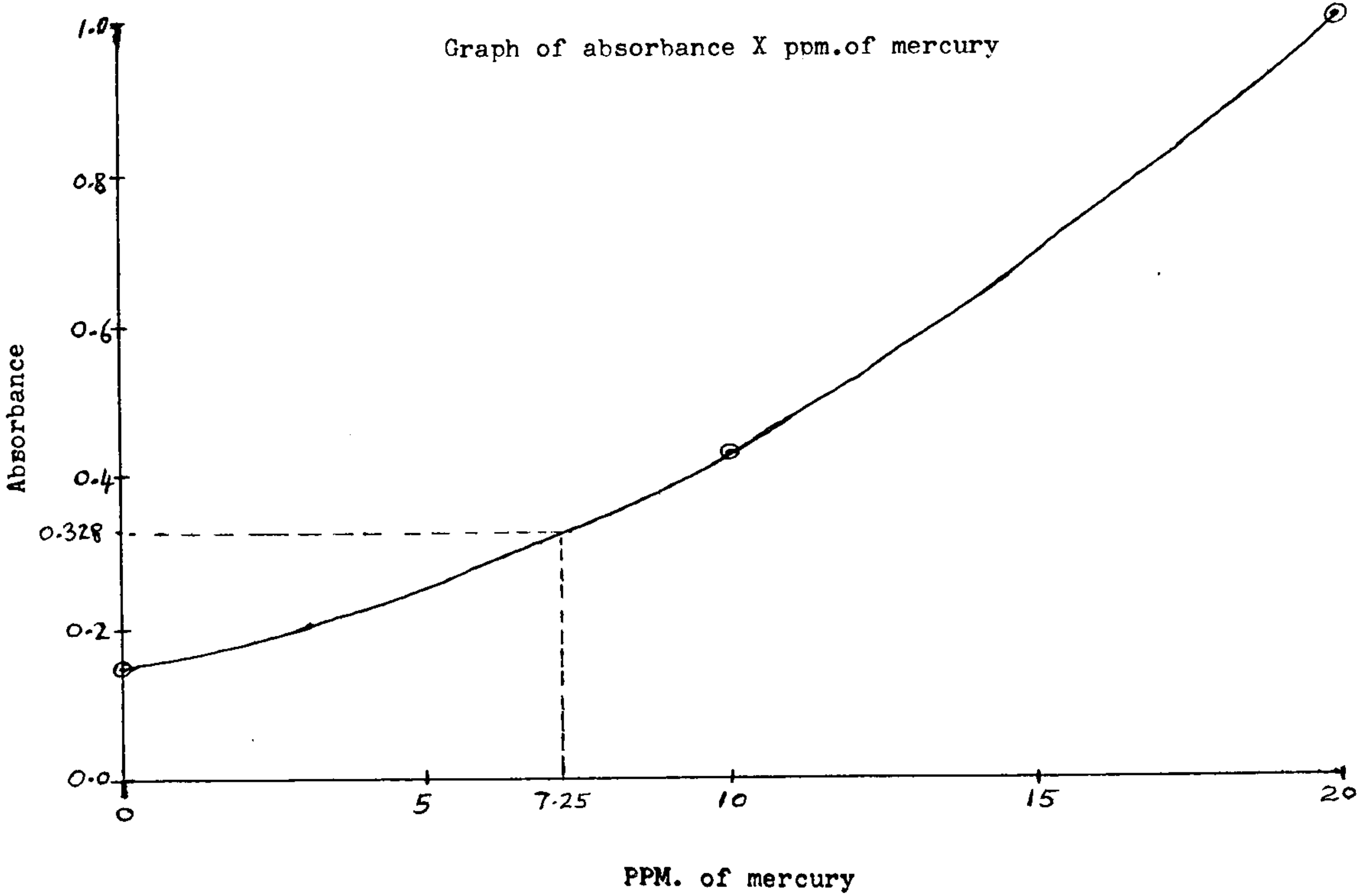
20. Ruchhoft, C. C., et al, U.S. Public Health Service Environ. Health Center, Cincinnati, Ohio.

21. Handbook of Analytical Toxicology, Edited by Sunshine, Chemical Rubber Co., p. 573

22. Burke, J. A., J. Ass. Off. Anal. Chem., 53, 355 (1970)


ELEMENT Hg
LAMP Hg
FUEL
OX
100
50
0
Extract
10 ppm. std.
5.8
Xtract
5.8 ppm
10
Extract
H2O
10 ppm Hg
20 ppm

Determination of mercury by atomic absorption spectroscopy



APPENDIX

MEMBERS OF THE SEMINAR, 1969-1970

Chairman of the Seminar:

George J. Halasi-Kun
Hydrologist
Columbia University

Steering Committee:

Charles H. Behre, Jr.
Professor Emeritus of Geology
Columbia University

Courtney C. Brown
Dean, Graduate School of Business
Columbia University

Laszlo Czirjak
Sr. Research Economist
Columbia University

Jewell M. Garrelts
Associate Dean of School of Engineering & Applied Science
Columbia University

Wesley J. Hennessy
Dean of School of Engineering & Applied Science
Columbia University

Kemble Widmer
State Geologist of New Jersey
Trenton, New Jersey

Members:

Enrique Gregorio Aisiks
Consulting Engineer
Buenos Aires, Argentina

Thad P. Alton
Intl. Financial Research, Inc.
633 West 115th Street
New York, N. Y. 10025

Charles G. Amato
Nuclear Engineer, Department of Environmental Protection
State of New Jersey
Trenton, New Jersey

Conrad M. Arensberg
Professor of Anthropology
Columbia University

Armando Balloffet
Civil Engineer, Lecturer of Columbia University
c/o Tippetts Abbett-McCarthy-Stratton, Engineers & Architects
New York

Joseph Barnea
Director, Department of Economic & Social Affairs
Resources & Transportation Division
United Nations, New York

Samuel S. Baxter
Water Commissioner
Water Department
City of Philadelphia

Byron Beattie
Expert on Forest & Watershed Management
United Nations
Manila, Philippines

Chaba Benedek
Chief Engineer
Swindell-Dressler Pan American Co.
Inez, Kentucky 41224

Paul Bock
Professor of Hydrology
University of Connecticut

L. Joseph Bollyky
Pollution Control Industries, Inc.
Stamford, Conn. 06902

Stephen K. Breslauer
NUS Corp. Environmental Safeguards Division
Rockville, Md. 20850

Wallace S. Broecker
Professor of Geology
Columbia University

Joseph H. Butler
Professor of Geography
State University of New York at Binghamton

George Claus
University of Vienna, Austria
Faculty of Medicine

Leonard B. Dworsky
Professor of Civil Engineering
Cornell University

Augustine O. Esogbue
Professor of Industrial & Systems Engineering
Georgia Institute of Technology

John Fabianek
Professor of Life Sciences
New York Institute of Technology

Rhodes W. Fairbridge
Professor of Geology
Columbia University

Richard Ford
233 Kings Highway E., Box 459
Haddonfield, N. J. 08033

James J. Geraghty
Groundwater Geologist
Port Washington, New York

Robert D. Gerard
Research Associate in Physical Oceanography
Columbia University

Samuel Gofseyeff
Civil Engineer
White Stone, New York

Alvin S. Goodman
Professor of Civil Engineering
New York University

Harry P. Gregor
Professor of Chemical Engineering
Columbia University

Guy R. Gresford
Director, Section of Science & Technology
United Nations, New York

M. Grant Gross
Professor of Oceanography
State University of New York at
Stony Brook

Isadore S. Grossman
Board of Water Supply of
New York City

William A. Hance
Professor of Geography
Columbia University

Ernest LeRoy Hendricks
Chief Hydrologist
U.S. Department of the Interior
Geological Survey, Washington, D.C.

John E. Harrison
Director, Environmental Quality
New York State
Department of Health

Allan Hirsch
U.S. Department of the Interior
Federal Water Pollution Control
Washington, D. C.

Robert Hordon
Professor of Geography
Rutgers University

Raphael Hurwitz
Board of Water Supply of
New York City

John A. Jones
Professor of Earth Sciences
Miami-Dade Junior College

William C. Kennard
Director, Institute of Water
Resources Research
University of Connecticut

Walter Kiechel, Jr.
Deputy Asst. Attorney General
Land & Natural Resources Division
U.S. Department of Justice
Washington, D. C.

Adolfo Korn
Mining & Mechanical Engineer
Section of Science & Technology
United Nations, New York

Martin Lang
Commissioner of Water Resources of
New York City

Gregory Lazarcik
Professor of Economics
State University of New York at
Geneseo

Cyrus Levinthal
Professor of Biology
Columbia University

Robert A. Lewis
Associate Professor of Geography
Columbia University

Daniel P. Loucks
Associate Professor of Water
Resources Engineering
Cornell University

Everett L. McLeman
U.S. HEW, Public Health Service
New York, New York

Francis M. McGowan
North Atlantic Division
Department of the Army Corps of
Engineering
New York

Ulrich Maniak
Professor of Hydrology
Technical University
Braunschweig, F.R. Germany

David C. Major
Asst. Professor of Econ.
Massachusetts Institute of Technology

David Miller
Groundwater Geologist
Port Washington, New York

Mahboob Mohammad
Sr. Lecturer of Chemistry
University Islamabad, Pakistan

Francis W. Montanari
Parsons, Brinckerhoff, Quade
& Douglas Engineers
Denver, Colorado

Nathaniel M. Perlmutter
Hydrologist
U.S. Geological Survey
Water Resources Division
Mineola, New York

George Redey
Civil Engineer
Englewood, New Jersey

Peter P. Remec
Professor of Political Sciences
Fordham University

Roland R. Renne
Associate Dean
University of Illinois

Hugh B. Ripman
Director of Administration
International Bank for Reconstruction and Development
Washington, D. C.

Oswald A. Roels
Sr. Researcher in Marine Biology
Columbia University

Harold R. Shipman
Head of Water Supply Division
International Bank for Reconstruction and Development
Washington, D. C.

Richard Skalak
Professor of Civil Engineering
Columbia University

Lawrence Slote
Grumman Aerospace Corp.
Bethpage, New York

Zdenek Slouka
Associate Professor of Political Sciences
Lehigh University

Floyd Taylor
U.S. Department HEW
J. Fitzgerald Kennedy Building
Boston, Mass. 02203

Nicolay P. Timofeeff
Professor of Geography
State University of New York at Binghamton

Michael A. Tirabassi
Asst. Professor of Operations Research
Stevens Institute of Technology

John Volkert
Associate in Geography
Barnard College

Grant F. Walton
Associate Professor of Environmental Sciences
Rutgers University

Leon W. Weinberger
Vice President
Environmental Control Management
Zurn Industries, Inc.
Washington, D. C.

William Whipple, Jr.
Director
Water Resources Research Institute
Rutgers University

Gordon R. Williams
Professor Emeritus of Civil Engineering
Massachusetts Institute of Technology
c/o Tippetts-Abbett-McCarthy-Stratton, Engineers & Architects
New York

John Winsser
Associate Professor of Biology
Long Island University

Lamar J. Worzel
Professor of Geology
Columbia University

Christopher Wright
Director
Institute for the Study of Science in Human Affairs
Columbia University

MEMBERS--Continued

Akhtar Yaseen
Chief of Laboratories
New York Medical College

Warren E. Yasso
Associate Professor of Natural Sciences
Columbia University, Teachers College

Leonard B. Zobler
Professor of Geology & Geography
Columbia University

Junior Members:

Lawrence A. Buck
Northport, New York

Kathy Hartman
Brooklyn, New York

Steve Hartman
Roslyn Heights, New York

William Jamieson
Amityville, New York

Peter P. Madri
Seacliff, New York

Yeshawant K. Purandare
East Farmingdale, New York

Frank Pecenka
New York, New York

Gerald W. Robin
Hicksville, New York

Martin S. Tanzer
School of Eng. & Applied Sciences
Columbia University