Integrating Water Quality Management Into Total Water Resources Management in Minnesota

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FOREWORD

This Bulletin is published in furtherance of the purposes of the Water Resources Research Act of 1964. The purpose of the Act is to stimulate, sponsor, provide for, and supplement present programs for the conduct of research, investigations, experiments, and the training of scientists in the field of water and resources which affect water. The Act is promoting a more adequate national program of water resources research by furnishing financial assistance to non-federal research.

The Act provides for establishment of Water Resources Research Institutes or Centers at Universities throughout the Nation. On Sept. 1, 1964, a Water Resources Research Center was established in the Graduate School as an interdisciplinary component of the University of Minnesota. The Center has the responsibility for unifying and stimulating University water resources research through the administration of funds covered in the Act and made available by other sources; coordinating University research with water resources programs of local, State and Federal agencies and private organizations throughout the State; and assisting in training additional scientists for work in the field of water resources through research.

This report is the twenty-third in a series of publications designed to present information bearing on water resources research in Minnesota and the results of some of the research sponsored by the Center. The study with which this report is concerned was designed to develop criteria for the management of water quality as an integral part of water resources management, and methodology for implementing such integrated management in the State of Minnesota. The concept of integrated water resources management is developed in some detail through many aspects such as the need for, and type of governmental involvement; institutional arrangements; judicial and economic policies; technical measures; the importance of socio-economic considerations; and the need to consider the widest possible range of alternatives. Approaches to this type of water resources management in three western European countries, Canada, and the United States are discussed. The existing arrangements for water resources management in Minnesota are compared with the criteria developed, weaknesses and deficiencies noted and alternative proposals made for their correction. The study provides information upon which the reorganization of water resources management in Minnesota may be undertaken.

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CHAPTER I

INTRODUCTION

The concept that water quality management is best carried out as an integral part of regional water resources management has, according to Kneese and Bower (1, p. 11)*, only recently been gaining acceptance in the United States of America even though it has been central to post-war legislation in a number of European countries. The Delaware River Basin Commission and the State of Wisconsin through its Department of Natural Resources have taken major steps in the direction of the implementation of this concept. Some evidence of at least limited acceptance in the State of Minnesota is to be found in the fact that the Minnesota Water Resources Review Committee (2) appointed by Governor Karl F. Rolvaag in April 1966, embodied this concept among its recommendations. This study was conceived with a view to developing the methodology with which to implement this concept in Minnesota.

I. NATURE OF THE PROBLEM

McGauhey (3, pp. 1-4; 4, pp. 5-8; 5) has traced the rise of the idea of quality as an important dimension of water resources management in America. The pioneering days, he states, saw quantity as the dimension of water to which men sought title. Neither the "riparian rights" concept inherited from ancient British common law nor that of the "first in use" established quality as a dimension of the property at stake. Quality, however, was not entirely ignored. The riparian owner was entitled to water that was not diminished in quantity or quality after upstream use. Forgetting the obvious absurdity of this requirement, taken literally, and examining the reference to quality, it is found that the concept of quality was then a gross one. Generally, it was one of "fresh" versus "salt" water with reference to the taste of humans. Other descriptive terms used included sweetwater, black-water, swamp-water, bilgewater and stumpwater. Early in this century, definite quality goals were established for drinking water in the interests of public health. However, as McGauhey points out, public drinking water supplies accounted for only about 7 percent of the water used by man and as a result there was little understanding of quality as a major aspect of water management.

According to McGauhey (3, p. 2), it has taken the "burgeoning urban-industrial - agricultural economy" which has forced the repeated use of a relatively constant water resource in answer to very rapidly increasing demands to bring home the realization that quality was a missing and very critical dimension of man's water rights. A brief discussion of some of the major contributory factors follows.

Population Growth and Distribution

Generally, population growth can be expected to result in at least a relative increase in total water use. Combined with other social and

*See References.

economic factors, however, the result has been one in which the rate of increase of water use has recently outstripped that of population growth. The major contributor to this trend has been the increased demand for industrial water use.

Population distribution further compounds the problems created by population growth. Barnhill (6, p. 3) has noted that by the year 1975, it is estimated that 90 percent of the nation's population will be living in towns, the suburbs of which will be subject to explosive growth. Minnesota's urban population in 1965 had already accounted for 64.3 percent of the total, according to Waelti (7, p. 16) whose forecast indicates that this percentage may well rise to over 80 by 1980. The higher living standards of urban areas achieved with the help of multiple baths, dishwashers, laundries, garbage grinders, etc. are accompanied by greater water needs. They are simultaneously associated with ever increasing volumes of wastes, stronger in pollutional characteristics, for ultimate disposal in streams. The net result of these population trends has been, therefore, a rapidly increasing demand on limited water resources, made even more so by their increased pollution. Repeated use of water has become a necessity and, with it, the need for control of quality has become more obvious. As stated by the Senate Select Committee on Water Resources (8, p. 5) after predicting that the nation's water demands will rise to about 888 billion gallons a day by the year 2000, or 81 percent of total streamflow, "most of this water is returned to the stream, and can be re-used many times, provided steps are taken to maintain its quality."

Competing Water Uses

Industrial. The tremendous growth of industry during this century has not only brought with it a large variety of water uses of its own but has been instrumental in the development of recreational water use. Associated with industrial growth has been the creation of increased leisure time for man with which to participate in water-based recreation and aesthetic enjoyment of water and related natural resources.

The water demands of the manufacturing industry are by far the greatest among industrial water uses while also increasing at the greatest rate. The demands of stream-electric power stations, says Sewel (9, p. 10), are also expected to increase at rates in excess of population growth. Industry's demands are for a variety of purposes including processing, washing, cooling and air-conditioning. The qualitative requirements are wide and varied; not so stringent for cooling and air-conditioning at one end of the scale but extremely exacting and different for each of a wide variety of industrial processes.

The quality problems of industrial water use are not only associated with the requirements for use but also with the waste waters discharged into streams. The wide variety of chemical and other wastes which do not respond to treatment in conventional municipal treatment plants has created many pollution problems.

During the past three decades the chemical industry has developed a wide variety of synthetic and petro-chemicals--detergents, insecticides,

herbicides, etc.--millions of pounds of which have been annually finding their way into streams (6, p. 3). This is the case of pollution caused by manufactured products as distinct from that of their by-products. Many of these chemicals are toxic, accumulate in fish, other aquatic biota, and wild-life in man's food chain. Little is known of the significance of the long-term effects of exposure or accumulation on the organisms found in the aquatic environment or man.

The power industry creates problems of air and water pollution by its radioactive waste discharges and the more recently recognized problem of thermal water pollution. With electric power demands being generally predicted to increase 100 percent every ten to fifteen years, nuclear power stations are expected to meet an increasing portion of these demands. Because of the serious risks that could be involved, proper environmental quality management must be undertaken.

Municipal. The water quality problems of municipal water uses are probably the best understood, having received earlier attention than all others. The linking of the spread of a number of gastro-intestinal diseases with contamination of drinking water supplies by domestic sewage during the past century gave the first efforts at water quality management a distinctly health-oriented emphasis. Solids removal, reduction of biological oxygen demand (B.O.D.), and disinfection have, until recently, been the major treatment components for municipal wastes. The inability of this form of treatment to remove plant nutrients, mainly phosphorous and nitrogen, has been dramatized by the excessive eutrophication that has been occuring in many of the nation's lakes including those in Minnesota. This has led to extensive research in the development and application of advanced waste treatment methods.

Recently recognized too has been the need for greater emphasis on the maintenance and propagation of fish and other aquatic life. The severe depletion of dissolved oxygen in streams and rivers caused mainly by the oxygen demands of municipal and some industrial and agricultural waste discharges must, therefore, be reduced and controlled. The trend towards the rapid growth of metropolitan complexes, described earlier, complicates the problem and makes its solution increasingly difficult.

Water is so important to man's physiological needs and to his maintenance of a healthy environment that it is not surprising that the first set of water quality standards has been those pertaining to domestic water supplies. The Public Health Service Drinking Water Standards (10), intended for application to waters used on interstate carriers, have received general acceptance as guidelines and criteria for all potable water supplies. They provide for protection of the water supplies from their sources through distribution systems and set limits for physical, chemical, bacteriological and radiological characteristics.

The physical requirements covering color, taste, odor, and temperature are designed to ensure that drinking water is aesthetically pleasing to the senses.

The chemical standards are of two types: (a) the "recommended" levels which should not be exceeded when more suitable supplies can be

made available, and (b) the "rejection" levels which, if exceeded, constitute grounds for rejection of the supply. In the first group are included arsenic, chloride, chromium, copper, fluoride, iron, manganese, nitrate, sulfur, total dissolved solids, and alkylbenzenesulfonate (ABS), a surface active ingredient of detergents. The second group includes arsenic, barium, cadmium, chromium, cyanide, fluoride, lead, selenium and silver. Of increasing recent concern are the trace elements which include arsenic, cadmium, selenium, lead, and others. The health effects of long-term ingestion of these trace elements are essentially unknown but may be significant. The likely cumulative effects of combinations of some of these elements and substances are even less known. There is also no definite guarantee that the listed chemicals are inclusive of all those that can be of health concern. The recent development and use of the wide and daily increasing variety of synthetic chemicals, many of which reach our domestic water sources, is yet another problem area. Little is known of the toxic nature of some of these synthetic chemicals to man or on the ecosystem.

The bacteriological standards use the coliform group of bacteria as indicators of the likely presence of pathogenic or disease producing organisms in our water supplies. There have been instances, however, which indicate that supplies meeting these standards are not always safe. Viruses and members of the salmonella species of organisms have been found in water in the absence of coliform organisms.

Radiological standards have been set for strontium-90, radium-226, and gross beta activity levels. The gross beta activity is another requirement which, when exceeded, constitutes grounds for rejection of a supply.

A very important consideration with respect to municipal water supplies is the fact that conventional water treatment processes change only the physical characteristics, very few of the chemical characteristics such as iron, manganese and perhaps total dissolved solids, and the bacterial count. Since most of the chemical elements including the "rejection" ones are unaffected by conventional treatment, domestic water quality requirements must to a large extent be met by management of the resource pool, McGauhey (3, p. 134).

Agricultural. Gross withdrawals of water for irrigation accounted for approximately 59 percent of the estimated 300 billion gallons withdrawn daily for all uses in the nation during 1954, according to the Select Committee on National Water Resources (8, p. 6). The Committee predicted reductions to 30 and 21 percent respectively in the years 1980 and 2000. Note, however, that the reduced percentages in 1980 and 2000, are with reference to much larger wholes, actually twice and three times the 1954 figure, respectively.

In terms of consumptive use (as distinct from withdrawals), the same source has shown irrigation to account for 95 percent of the total in 1954 with predictions of 88 and 81 percent in 1980 and 2000, respectively. These do not include predicted onsite uses for watershed improvements, and swamp and wetlands in the last two years mentioned.

The situation in Minnesota is somewhat different with irrigation using a mere 2 percent of the 424 million gallons withdrawn daily in 1950 and predicted to increase to 2.6 percent of 626 million gallons per day in 1975 (11). Despite this lower relative position vis-a-vis the nation, irrigation water is critical to a number of the state's crops in many dry years.

The above shows that irrigation is a major and important use of water and is likely to continue to be so in the foreseeable future. Further, it shows that irrigation is by far the largest consumptive user of water, a very important fact in view of the rapidly increasing demands on this fixed resource.

Water for irrigation, as it is with other uses, must meet required quality criteria, e.g. with respect to salinity and specific mineral content. The return waters (after use) exhibit considerable quality degradation in addition to the volume reduction already discussed, mainly as a result of evapotranspiration and leaching of soils. McGauhey (3, p. 64) has reported Eldridge's summary of these degrading effects to include increased salinity (as much as five-fold), greatly increased hardness, total dissolved solids, somewhat increased nutrients (phosphorous and nitrogen), tastes, and odors. These return waters also include significant amounts of insecticides and herbicides.

As stated earlier, nutrients contribute to algae and other plant growth in receiving waters while accumulations of insecticides and herbicides can create problems for the aquatic environment and, ultimately, for man at the top of the food chain.

Farm wastes, particularly those from cattle feed lots, have recently been gaining attention as significant sources of water pollution. In the absence of adequate control measures, the problem is likely to grow in magnitude with the national trend towards larger farms and the greater use of feed lots with their characteristic large accumulations of animal wastes.

Industries which process agricultural products constitute another source of water quality problems resulting from their very strong waste discharges.

Recreational. Water-based recreation, as stated earlier, has been growing in significance in recent years. According to the Senate Select Committee on National Water Resources (8, p. 4), it is expected to increase manifold in the foreseeable future.

Water-contact sports such as swimming and skiing generally require the absence of substances (including pathogens) which are dangerous when ingested. This is in addition to the other aesthetic requirements of all recreational uses pertaining to freedom from obnoxious suspended or floating material, objectionable color and foul odors. Eutrophication of lakes resulting from their fertilization with nutrients is of special concern with respect to recreational water uses because of unsightly algal growths and their associated objectionable odors.

Oxygen requirements are among the most important for aquatic life including fish. Hence the major concern with the deoxygenating effects of sewage disposal in surface waters. The organic pesticides are another source of concern with respect to aquatic life and the ultimate effects on human consumers of fish. A wide variety of chemical substances found in water may have deleterious effects on fish propagation. McGauhey (3, p. 147) has listed McKee and Wolf's summary of these substances and their threshold concentrations. Radionuclide concentrations in water also present problems for fish propagation since further concentration of some of these elements takes place in fish thus increasing the exposure to consumers. Straub (12, pp. 87-90) has discussed some observed concentration of radionuclides by aquatic organisms and the resulting need to reduce the levels of radioactive releases to streams below appropriately modified maximum permissible concentrations. Klein (13, p. 77), in listing a series of coal-tar derivatives which are toxic to fish and cause objectionable tainting of fish flesh, has pointed to yet another source of concern for recreational and commercial fishing.

Wild life, both birds and animals, have been known to be poisoned by toxic forms of blue-green algae found in eutrophic lakes. Highly mineralized and oil polluted waters also pose problems to aquatic life. With respect to oil pollution of waters, navigation and off-shore oil-well drilling have recently been seriously implicated.

Power, navigation, and flood control. The modification of stream flow by the construction and operation of dams for hydro-electric power, navigation and flood control can have both beneficial and deleterious effects on water quality.

When such modifications are used for low flow augmentation, water quality may be enhanced to the extent that greater dilution is provided in streams for waste assimilation. On the other hand, should the water be released from the oxygen depleted lower depths of a stratified reservoir the water quality of the stream may be deleteriously affected.

Flow control structures also alter the volume and nature of sediment transported by streams with consequential effects on stream biota. Dissolved oxygen content may be increased through the operation of dam outlets, turbines and other control works. Temperature control may also be achieved this way.

The Federal Council for Science and Technology Committee on Water Resources Research (14, p. 64) has noted that the effects of changes in water quality on Lake Erie as a result of water control structures have been marked.

Reference has already been made to the involvement of navigation in the pollution of surface waters by oil discharged or spilled into them. The massive oil spill from the oil tanker Torrey Canyon which ran aground off the English coast in March 1967, ruining English and French beaches, is an example of the seriousness of this problem. Another similar recent incident involved the leakage of oil from a barge that ran aground in the Mississippi River near Alma, Wisconsin in June 1969 (15).

Human waste and chemical discharges from navigational vessels of all types can also have adverse effects on water quality. The massive fish kill that occurred in June 1969 on the River Rhine (16) was later attributed by officials of the West German Health Ministry (17) to have been caused by a 220-pound sack of Endo Solvan, an insecticide, thrown, dumped or washed accidentally into the river from a ship or barge.

Water quality criteria for various uses have been discussed in considerable detail in the Report of the National Technical Advisory Committee to the Secretary of the Interior (18).

Conflicts of Water Uses

Competing water uses, their quality requirements and their effects on water quality have been discussed in the preceding sections. The conflicts associated with these various uses are numerous. This section will serve to point up some of these conflicts with particular reference to water quality and the need for an integrated approach to water resources management.

Firstly, all uses have some residual effect on water quality and despite, or in spite of the riparian concept of water rights, downstream users will inherit water of impaired quality. As stream pollution increases with multiple use and reuse of water, the socio-economic effects on downstream users can become appreciable. For instance, public health and economic development may suffer.

There is the conflict of development versus conservation and aesthetic enjoyment. Should rivers and riverain areas be maintained in their primitive states for aesthetic enjoyment or should they be developed instead for water and power supplies or used for waste disposal?

Should the quality of all surface waters be maintained such as to satisfy the requirements of all possible uses and is this practicable in view of the widely varied requirements involved? If not, which set of quality requirements should predominate over all others?

Uncontrolled sewage disposal into surface waters may ruin the quality (bacteriologically and otherwise) of such waters to the extent that the waters may be rejected for use as drinking supplies. Even after conventional sewage treatment, the disposal of effluents into lakes may result in such extensive algal blooms as to severely limit, if not completely prevent, the aesthetic enjoyment of the lakes. Waste assimilation in streams uses up the oxygen that is necessary for the propagation of fish and other aquatic forms. Oxygen on the other hand is undesirable in cooling water since it may cause considerable corrosion of pipes and other conduits. Does this then mean that entire streams or reaches of streams should be zoned for specific single or multiple sets of uses?

These conflicts could be pursued ad infinitum though this is not considered necessary to demonstrate that quality considerations must be of great importance in the decision-making processes of water resources management.

In summary,

1. Water quality has been assuming greater importance due to the pressures of population growth and competition among a wide variety of uses on a limited resource.
2. With each water use is associated quality considerations pertaining to both the water extracted from and that returned to the resource.
3. These considerations pose many conflicts, thus creating a very complex management situation.

The above have been among the major factors contributing to the growing recognition of the need for comprehensive water resources management in which the qualitative and quantitative aspects are fully integrated. This approach contrasts sharply with that extant in Minnesota and the United States generally, in which the qualitative and quantitative aspects are managed independently and are subject to great fractionation.

The Federal Council for Science and Technology (14, p. 12) described quality management as being "central to the task of providing an adequate water supply." The Council further stated that even if water were fully abundant throughout the United States, the sequential use of the resource by cities and industries would make quality rather than quantity apt to limit use.

Further evidence of the attitude of Federal Government on integrated water resources management is to be found in President Johnson's statement (19, p. 555) with respect to the transferral of the Federal Water Pollution Control Administration and many related functions from the Department of Health, Education, and Welfare to the Department of the Interior that

> ... the purposes of the reorganization, ..., were to bring about elimination of duplication of activities as well as to bring water pollution control activities under the jurisdiction of the agency having responsibility for river-basin planning, multiple-purpose water and related land resources projects and water resources research.

Researchers of considerable national eminence such as Kneese and Bower (1) and Craine (20) have strongly advocated an integrated approach to water resources management.

The existing legal, institutional, and administrative arrangements developed on an ad hoc basis by many states over the years would not readily accommodate an integrated approach to water resources management. Research is necessary for developing the criteria for such an approach and the methodology for its implementation.

The area dealing with the methodology and criteria for water resources planning, interpreted to include the area of this research project, was described by the Federal Council for Science and Technology (13, p. 9) as being

> possibly the most promising area of research in terms of immediate and long-term payoff ... Yet this area can be described as the most neglected area in the present research program ... [and] receives roughly 1 percent of the current total research effort.

The Water Resources Research Act of 1964, Public Law 88-379, and the Water Resources Planning Act of 1965, Public Law 89-80, have provided States with the stimuli needed to undertake the research and to plan for meaningful water resources management.

The State of Minnesota has been beset with the problems of the rapidly growing urban - industrial - agricultural economy. Some 30 major State and Federal governmental units and more than 50 others are concerned with water resources in the State (21). There are ample evidence of the ad hoc measures adopted in the past. It was not surprising, therefore, when the Minnesota Water Resources Review Committee (2, p. 5) in October 1966, recommended to former Governor, Hon. Karl F. Rolvaag, that "water quality management be more fully integrated with the management of water resources for other uses through the statewide water resources plan."

II. THE STUDY

Objectives

Recommendations, to be truly worthwhile, must be translated into tangible accomplishments. The problem of interest must be carefully analyzed, goals defined and methodology established for achieving these goals. This study is aimed at providing the tools with which the recommendation quoted immediately above may be translated into an accomplishment.

The study has as its objectives:
1. The establishment of criteria for integrated water resources management.
2. The development of methodology for implementing such management in the State of Minnesota.

Review of Current Research

An inquiry of the Science Information Exchange, Smithsonian Institution in 1966 produced no evidence of similar studies being undertaken in either Minnesota or the United States.

The State of Minnesota. Research projects then being undertaken in Minnesota fell into the following categories: (a) the use of aquatic organisms as indicators of water quality, (b) the effects of various processes, waste discharges, and agricultural and forest practices on aquatic organisms, and water quality, (c) inventories and studies of aquatic organisms, (d) pollution travel in soils, and (e) hydrologic parameters controlling a specific water use.

Since then, the Public Administration Service published a report (22) on Executive Reorganization in Minnesota. This study was aimed at

streamlining the very cumbersome and confusing executive organization which resulted in "needless inefficiency, wasted human and material resources, and slow response to changing public needs." It recommended, among other things, the creation of a Department of Natural Resources to be structured around the present Department of Conservation. This new department would absorb the functions of various existing departments in the areas of air, water and land resources management and result in the abolishment of some existing agencies, including the Minnesota Pollution Control Agency. In effect, it merely lumped existing functions together and pruned agencies. It did not consider a full set of criteria for an integrated water resources management program, examine existing policies with a view to making necessary changes in accordance with the developed criteria. It did not adequately consider the problem of integrating water quality management with the other aspects of water resources management.

The Minnesota Water Resources Research Center has recently referred (21, p. 98) to a research project initiated during fiscal year 1970 entitled "Water Resources Administration in Minnesota." The objectives of this project are

> (a) to inventory, appraise and evaluate water resource legal institutions, administrative structures, and public administrative processes and techniques in Minnesota and (b) to make recommendations which will be more conducive to achieving coordinated water resource programs.

Further description of the project seems to indicate its major concern with the coordination of administrative units of government, and with administrative costs. It will not be concerned with the socio-economic and ecological considerations of an integrated water resources program nor the criteria for such a program.

The Nation. The listed research projects in the United States other than Minnesota fell into the main categories of: (a) the application of systems analysis to problems of water resources management, (b) the mechanics of water movement through hydrologic units, (c) the effects of storage and main-river impoundments on water quality, and (d) the economics of water supply and water quality.

The above review indicates that recent research has been concerned mainly with very narrow aspects of water quality and quantity control. It has neglected truly comprehensive water resources management embracing all possible uses of the resource and all the socio-economic and ecological factors.

During the last two years Kneese and Bower (1) and Craine (20) published penetrating analyses of the problem of integrated water resources management in the context of the present study.

It is hoped that the present study, in addition to providing the basis for constructive action in Minnesota, will add to the general knowledge in this area and provide other States with the basic principles with which to attack similar problems.

Organization

The remainder of this report has been divided into five chapters. Chapter 2 discusses the concept of integrated water resources management including water quality management, technical measures, and administrative policies. Also included in this chapter are a number of definitions considered necessary to the development of the thesis.

Chapter 3 is concerned with institutional arrangements for water resources management. Criteria for management institutions and the roles to be played by governments of general jurisdiction in the context of the United States (Federal, State, and local) are suggested. Finally, some approaches to integrated water resources management in some foreign countries and parts of the United States are examined.

Water resources management in the State of Minnesota is the subject of Chapter 4. This chapter takes an historical look at the subject, examines the existing situation, including the legal, institutional, administrative arrangements and some of the major problems. Comparisons are made with the criteria of Chapter 3 to bring out deficiencies and needs.

Chapter 5 considers a number of alternative approaches to integrated water resources management in Minnesota, their advantages and disadvantages.

The developments of the previous chapters are summarized in Chapter 6 and findings and research needs indicated.

The background information for this study has been assembled from a wide variety of sources including a review of the literature and correspondence with officials of various agencies in the United States of America, Canada and overseas. Personal visits were made to the Delaware River Basin Commission (DRBC), the Ohio River Valley Sanitation Commission (ORSANCO), the Ontario Water Resources Commission, Resources for the Future (RFF), and to various Federal and State agencies in Minnesota and across the nation. Information collected during an unrelated visit to Great Britain during the autumn of 1965 has also been used.

The early phase of the study included collaboration with a Task Force of the Water Resources Coordinating Committee, Minnesota State Planning Agency, in preparation of a report entitled "Background Information for Framework Statewide Water and Related Land Resources Planning in Minnesota" (23). Extensive use has been made of this report and its several working papers, supplemented by personal visits to Federal, State, and local agencies in the preparation of Chapter 4.

Attendance of a variety of hearings, conferences, workshops and symposia, and meetings across the State of Minnesota and elsewhere in the nation also provided information. A newspaper-clipping file maintained over the past three years served as a means of keeping in touch with current problems in the State, the nation and abroad.

CHAPTER 2

CONCEPT OF INTEGRATED WATER RESOURCES MANAGEMENT

Many references have been made to the phrase "integrated water resources management" without defining it, except to say that it embodies the integration of water quality management with that of the other aspects of water resources management. This has been deliberate since it is felt that more than a single sentence or paragraph is needed to define the phrase. In view of the importance of this phrase to the study, this entire chapter is being devoted to developing the concept of "integrated water resources management."

The objectives, characteristics and important features of water resources management are examined. Also examined is the constituent, water quality management--its technical and engineering, and policy measures. Rather than simply placing water quality management with the other constituent parts of water resources management to complete the whole, it is proposed that water quality management be used as the core around which to build, and motivating force with which to ensure a truly integrated water resources management.

1. WATER RESOURCES MANAGEMENT

Historical Trends

Historically, the concept of water resources management in the United States has not been static, but in a state of flux, changing with shifts in the objectives of water resources development. These changes have been traced in many sources (19, pp. 426-467; 24, p. 28; 25, pp. 2-7). Early settlers emphasized the development of specific resources for single uses, with transportation, irrigation and later flood control being dominant. During the early 20th century, river basins came to be recognized, in many cases, as the best units for planning, and the idea of multipurpose projects fashionable. The Hoover Dam became the typical example of multipurpose regulation with integration of benefits and telescoping of costs as the attractive features of this type of development.

The 1930's saw the establishment of the Tennessee Valley Authority (TVA) as the prototype for comprehensive development of an entire drainage area through the coordination of several multipurpose projects. Benefits to the region and nation as a whole were the expressed goals of such development rather than the quantitative accomplishment of engineering functions.

The 50's and 60's have seen the Federal Government assuming an increasingly greater role in fostering comprehensive long-range planning, the consideration of all types of water demands and development possibilities, and the control of water pollution. The nation's concern has widened considerably with time from the narrow specific interests centered on navigation and irrigation to the assurance that all regions share in the national growth and individuals have the opportunity of enjoying the scenic and recreational pleasures of the natural environment.

Definition

The concept common to most of the very recent definitions of water resources management is that of a production function in which the resources are viewed as inputs to the management system and the resulting combination of water services are the outputs.

Putnam and Wilkinson (26, p. 66), for instance, cite the customary definition of water management as

> ... that activity which deals with the intelligent development and utilization of a society's water resources quantitatively and qualitatively, whether they be on the earth's surface, above it, beneath it, or in the oceans.
> The phrase "development and utilization" means on the one hand procurement, whether through the tapping or diversion of surface or subsurface water, its storage, movement, desalination, or rennovation [renovation], and on the other hand the application of this water for such diverse purposes as recreation, agriculture, transportation, stream dilution and environmental maintenance and improvement, waste disposal, cooling, as a raw material feed, or for domestic use. "Intelligent" simple [simply] means in this sense "wise" - development and utilization in such a way as to insure a blend of socio-economic satisfaction for all users of water, present and prospective.

Kneese and Bower (1, p. 6) similarly see water quality improvement, energy, water supply, irrigation, navigation, water-based recreation opportunities, and flood damage reduction as the resulting outputs from the management of water resources systems which are comprised of individual and collective structural and non-structural measures. Among the structural measures are reservoirs, treatment plants, levees, groundwater recharge facilities, irrigation facilities and power plants. Flood warning networks, zoning, standard setting, withdrawal fees, and effluent charges are listed among the non-structural measures.

For the purpose of this study, the concept of water resources management has been best developed and expressed by Craine (20, pp. 2-22). In a sentence, he defines water management as "a governmental response to the growing need to maximize the productivity of specific hydrologic resources." He later develops on this, emphasizing that "water management represents an advanced state in government's involvement in water resources" and that it suggests the production function concept to which earlier reference has been made. His representation of the production function concept, based on suggestions from Blair Bower, has been reproduced in Figure 1. The "goods and services" derived from water management actions are classified by him into two general kinds: (a) those that are overtly bought and constitute the main reasons for the specific actions taken, and (b) the incidental benefits or by-products of providing the overt services. The former services, he points out, have the characteristics of public utility function.

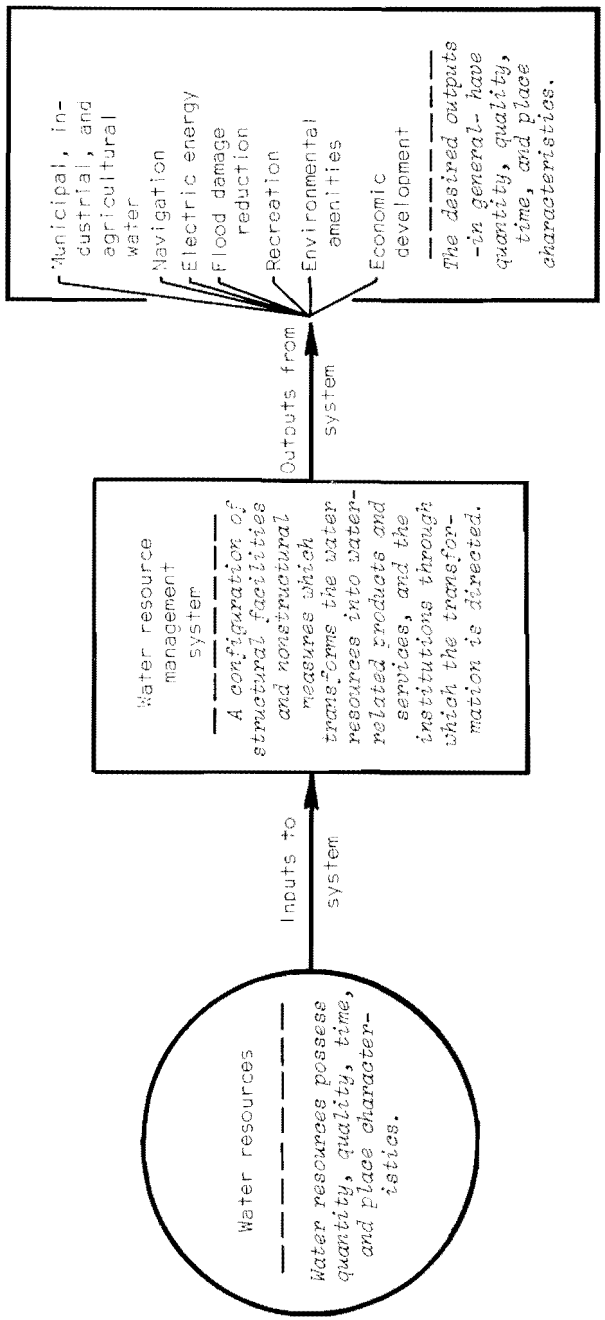


FIGURE 1. A GRAPHIC PRODUCTION FUNCTION FOR WATER MANAGEMENT (20)

There are two very important features of Craine's concept of water resources management that make it stand out from the others. Firstly, he sees it as a governmental response, indeed an *advanced state* in government's involvement in water resources. This point will be further developed later. Secondly, he shows water quality to be a characteristic of both the inputs--water resources, and the outputs--goods and services, of the management system. This differs from Kneese and Bower's concept, stated earlier, which merely shows water quality as one of the outputs (to be distinguished from a characteristic of the outputs) of the management system.

The advantages of Craine's analysis are: (a) it is more technically precise since the water resources inputs to the management system do have specific and very important quality characteristics that considerably influence the management actions taken and, therefore, cannot be ignored, and (b) by showing quality as characteristic of both the inputs and outputs, it automatically makes quality management an integral part of water resources management, taking its proper place in all transitions from input to output through the management system. Further, the outputs of management may include either or both water quality improvement and degradation depending upon the intended water use or combination of uses. Water quality improvement considered merely as one of many outputs from the management system may result in the perpetuation of separate water quality management, or that of the currently popular pollution control which neglects many quality management techniques. The distinction between pollution control and water quality management is considered later in this chapter.

Need for Governmental Involvement

Craine (20) has stressed the importance of governmental involvement in water resources management. He lists and describes five important characteristics that favor public (governmental) intervention in water affairs. These characteristics, which he points out also establish conditions for effective governmental involvement, are: (a) multiple use, (b) interdependencies in the hydrologic system, (c) regional disconformities, (d) scale economies, and (e) natural monopoly and pricing. The following is a discussion of these characteristics based on Craine's analysis (20, pp. 7-12).

Multiple use. The term multiple use in this context embodies both the reuse capability of a given unit of water and the multipurpose use of single water control structures. Relative to the former, the same unit of water that generates electricity may also be used for domestic and industrial water supply and/or improve water quality and recreational opportunities. Management must, therefore, be concerned about any likely sources of water losses such as evaporation, transpiration and diversion, and/or quality deterioration which may reduce the reuse potentiality of the resource. Wastage of all forms and the allocation of water to low-priority uses are other critical factors, all of which must be considered if efficient management is to be achieved.

An example of a multipurpose structure is a reservoir that is used to generate electricity, store flood waters, provide water recreation, facilitate navigation and provide water supply for domestic, agricultural and other purposes. Management must seek to reconcile and/or minimize the conflicts of multiple use described in Chapter I, as well as to obtain the most efficient combination of uses. It must also recognize that circumstances will not always favor multipurpose development but may in some cases require specialized uses of streams, sections of streams, impoundments, or aquifers.

Interdependencies in the hydrologic system. Water use, regulation, and development create a wide variety of interdependencies in hydrologic systems. Reservoir construction, for instance, modifies downstream flow behaviour and water quality and may, therefore, place constraints on downstream water uses. Upstream waste disposal may also considerably limit the downstream uses of a stream.

The appropriate physical unit for integrated water resources management thus becomes a vital factor. The river basin gained popular recognition with the establishment of the Tennessee Valley Authority as the physical unit best suited for water resources management. As pointed out by Craine (20), however, it is not always sufficiently definitive for this purpose. In some cases, two or more discrete hydrologic units may be contained in a single river basin if such a basin crosses distinct climatic regions. This is the case with many rivers of the American Great Plains, the upper reaches of which are in arid climatic areas and the lower in humid areas. Conversely, engineering construction works may, in effect, combine two or more drainage areas into one hydrologic unit. Hydrologic units should generally be the bases of areas organized for integrated water resources management. However, as stated by Maass (27, p, 603), the technologic function of planning [and management] for large river systems with many tributaries, such as the Mississippi, will tolerate segmenting and skeletonizing. The adoption of smaller management units than the hydrologic unit may be satisfactory and even desirable in such cases.

A special interdependence exists between ground water and surface water resources, often ignored in the past but which should receive fullest consideration. Ground water resources in many areas exceed the potential of surface water resources. The better quality and lower development costs of ground waters may, in many instances, indicate their preferential use over surface waters. Use of the two sources should be coordinated as dictated by the prevailing quantity and quality, costs, and preferences. In addition, ground and surface water units may be hydrologically related and part of the same hydrologic unit. The use and misuse of a surface water unit may have adverse effects on a contiguous ground water unit and vice versa. It is, therefore, of great importance that surface and ground water resources be managed conjunctively.

These hydrologic interdependencies which relate not only to competing developmental purposes at a given site but also to those at different sites in the same hydrologic unit must be consciously managed on the basis of their social and economic consequences. This is necessary if

unplanned "spillover" effects from one site of use to the next are to be avoided. The spillovers (damage costs and/or benefits), to the extent that they can significantly distort user decisions, should be evaluated and incorporated into the regional management process.

Regional disconformities. Craine correctly sees the disconformities that exist among different regional systems as presenting a major difficulty in organizing for the management of water resources. He points out that while water management must accomodate the "spillover" effects stemming from interdependencies within the hydrologic unit, a hydrologic unit is essentially only a unit of supply and seldom conforms to regions of discrete "demands" for water development services. The benefits of water-related recreation, for example, are usually not limited to occupants of the physical hydrologic region but extend well outside of it depending upon the mobility limitations of recreationists. Municipal, industrial, and irrigation water supplies are often withdrawn by different agents, from several different points in a hydrologic system, distributed to different clientele with varying geographic jurisdictions and may finally be discharged into another hydrologic unit. The productive capacity of a hydrologic system must, therefore, be articulated with the "demands" of the service areas, each of which constitutes a separate socio-economic system.

Further compounding the problem is the fact that the jurisdictions of general government which provide the legal and administrative operational framework, and the financial backing for water resources management seldom conform to either hydrologic or demand regions.

In agreement with Craine (20, p. 11), it is felt that

> The hydrologic system should properly reflect the production possibilities and constraints, while the demand sector should be so organized that it can express demand in consideration of production costs as well as the legal policy constraints of the governmental system. The procedural linkages by which these components are articulated are the key to establishing institutional arrangements that will enable efficient water management.

Scale economies. The use of large scale facilities and management systems can often effect significant economies in the capital intensive operations of water resources management. Such economies are commonly referred to as scale economies and are essential to efficient water management. Traditional institutional arrangements in the United States do not, however, favor the achievement of such benefits because of severe jurisdictional fragmentation. New approaches must be flexible enough to encourage large scale operations and their associated scale economies.

Natural monopoly and pricing. Craine describes water resources and the production of water services as natural monopolies. The absence of a competitive market, he says, results in consequences which are often the justification for governmental intervention in water resources management.

While some water services are marketable and may be treated as the outputs of public utility, others are not and costs chargeable to these services are usually met from taxes. Management has the difficult task of deciding which jurisdictions to tax.

The current pressures for efficiency of water use is causing concern to be expressed about wastage. The "free good" concept of water must become something of the past. Nor is it sufficient to use water charges based simply on the cost of facilities or their operation. Prices should reflect the value of the water in use, it is felt, if inefficiencies are to be reduced. Such a pricing policy, it is recognized, will require changes in existing institutions.

In summary, the nature of the above five characteristics of water resources clearly limit the efficacy of private enterprise in the management of those resources. The decisions that must be made on the many complex issues raised can have such far reaching and profound socio-economic repercussions that they should be the concern of governments. Resolution of the conflicts of multiple use would be unwisely left to private enterprise. As Craine (20) points out, independent water use and development agents cannot be expected to take account of the spillover effects (costs and/or benefits) of their actions. Regional disconformities and the capturing of scale economies traverse the interests of many communities and public jurisdictions and are properly the concern of high enough level of government. The monopolistic characteristic of water resources and the production of water services is one of the strongest reasons for governmental involvement.

There is, however, a sixth characteristic of water resources that favors public intervention and also influences the nature of that intervention. This is the characteristic that makes water management decisions of relevance to air and land resources management, and vice versa. These "environmental interrelationships" are discussed in the following section.

Environmental interrelationships. The effects of land use on water resources have been discussed in some detail by Bullard (28). He sees the principal effects as being concerned with the amount of surface flow, the timing and magnitude of flow maxima and minima, and with water quality. Agricultural land use and forest development both disturb the soil and can result in considerable erosion and hence sedimentation in streams. Cross-country construction of roads, highways, power lines and pipe lines may also be similarly implicated in water quality degradation.

The paving and roofing of large areas, characteristic of urbanization, produce almost 100 percent storm runoff thus altering stream flow characteristics while also flushing away any eroded material.

Many of the most common pesticides used in modern agricultural practices are toxic in the aquatic habitat at levels of less than one milligram per liter (mg/l). Great concern has been expressed recently over the very slow rate of biodegradation of DDT and other pesticides, and of their accumulation in the fat and flesh of fish and other aquatic organisms thus posing a threat to consumers (29, p. 23).

Agricultural land use is also implicated in the leaching and washing of nitrates and phosphorous from fertilizers into surface waters, and nitrates into ground waters. Runoff from agricultural lands can be major contributors to the overfertilization or eutrophication of lakes with the resulting excessive algal growths. Animal manures particularly from feedlots and dairy wastes are other sources of stream pollution.

Other land use effects on water resources management may stem from the location of industry. Kneese and Bower (1, p. 10) state that the location of an industrial park and its effluent outlets immediately upstream of a municipal water intake may create damage costs in excess of the benefits from the new industry.

The above points to the need for land and water management institutions to be such as to ensure full evaluation and accounting for those interrelationships. This is not to say that these resources must be managed by a single agency but that specific arrangements must be made for taking these interrelationships into account.

Air quality may also be affected by water management decisions. The burning of wastes, instead of discharging them into streams, while improving water quality can adversely affect air quality. On the other hand, the burial of wastes to avoid burning them can create problems for both land and water resources management. Of growing concern recently has been the effects of nuclear power plant releases on air and water quality and the aquatic environment.

Decision-making relevant to these interrelationships can have profound effects on many communities and jurisdictions and ought to be the responsibility of governmental units.

Governmental Techniques for Effecting Water Resources Management

The decision having been made that governmental intervention is necessary in water resources management, the next logical question concerns the extent of the involvement. What are the techniques at governments' command, and how and to what extent should they be exercised?

Craine (20, pp. 12-19) postulates five techniques, combinations of which permit governmental entry into the production function of water resources management in varying degrees. These techniques are: (a) water resource intelligence, (b) identification of water resource potentials and planning, (c) regulation of water use, (d) development of the water resource, and (e) organization of regional distribution (marketing) and disposal systems. The following discussion of the significance of these techniques will explain and justify the statement, earlier emphasized, that water management is an advanced stage of governmental involvement in water resources.

Water resource intelligence. The management of water resources, like that of any other resource, is fundamentally dependent upon the availability of facts on which to base decisions. In this case, these facts are comprised of physical, social and economic data.

The collection and dissemination of hydrologic data have often been one of the first activities of governmental involvement in water resources. Also included among the physical types are meteorologic and qualitative data. As pointed out by Craine, the provision of these types of data tends to be the least intrusive upon individual freedoms. The data provide facts and guides to private as well as public development agencies.

The provision by governments of social data such as population distribution and growth trends, and economic data is of more recent origin. Such data may be aimed at more specific problems and often serve organized public planning efforts, the general public, and independent enterprises.

Government's intelligence function may begin as merely a service to those who seek it and continuously grow to the stage where it is a continuous network of data of all types, including monitoring and feedback data relevant to comprehensive management decisions. Craine sees the development of this latter type of network as better serving independent water development agents (why, isn't stated) but also as being of primary importance to government operations charged with responsibilities for water management.

Identification of resource potentials and planning. This technique is essentially an extension of the intelligence activities just outlined. As pointed out by Craine it may serve a variety of purposes according to the chosen extent of governmental involvement. At one end of the spectrum, government's chosen role may be limited to resource inventories (including human and labor resources), projections of growth in demands, suggestions of alternative responses to demands, and the preparation of reconnaissance plans. At the other end of the spectrum, according to Craine, government takes over as a public entrepreneur and its planning is such as to provide specifications and schedules of actions to be taken.

A fully integrated water management program would require an involvement that more resembles that latter approach. It would require the development of a comprehensive plan based upon extensive data collection, flexible enough to accomodate changing trends and demands, and with built-in provisions for continual revision to meet those trends and demands. All actions taken should be examined within the framework of such a plan. The requirements of sound water quality management dictate the need for such an approach. This will become more evident following the discussion on water quality management in this chapter.

Regulation of water use. Craine lists three principal ways of regulating the use of water (including water quality). These are: (a) promulgation and enforcement of standards permitting and constraining water use, (b) administrative allocations of water, and (c) pricing such as to influence the kind, amount and timing of use. These, he points out, are not mutually exclusive but rather can be most effective when conjunctively used to supplement one another.

Current regulatory measures are based almost entirely on the first two ways and are generally inadequate for present day needs. An integrated management program requires greater reliance upon use charges as a regulatory tool. These charges should cover the full range of water uses including withdrawals, disposals and in-stream water uses. As stressed by Craine, Kneese and Bower (1), and many others, pricing should reflect the true value of the water service and, under such circumstances, can be a very useful regulatory tool.

Development of the water resource. The trend of change in the objective of water resources development has earlier been traced from the narrow goal of single specific services to the much broader present day one of maximization of the capacity of entire hydrologic systems to serve people. Effective water management, states Craine, requires that institutional arrangements be such as can provide development facilities designed and operated to avoid spillover costs and to take advantage of spillover benefits stemming from the interdependencies of the hydrologic system.

He sees three basic methods of providing coordinated development facilities: (a) direct public planning, design, construction, and operation of development facilities, (b) public regulation of all aspects of new development projects (planning through operation) of independent agents, and (c) contractual agreement between public agency and independent operators of existing facilities. While Craine did not specifically say so, it should be understood that the reference to development facilities and projects includes those aimed at water quality management. Truly effective management would require the combined use of all the methods in a supplementary manner. On occasions when methods (b) and (c) fail to accommodate all problem areas and consider all alternatives, then the public institutional arrangements should be such as to permit the implementation of the first method. In the absence of such an approach management would be incomplete.

Organization of regional water distribution and disposal systems. The tendency for public or governmental involvement in the distribution and "marketing" of water services and the disposal of used water to be merely peripheral is seen by Craine as a shortcoming. He cites three facts as significantly favoring more direction over water distribution and disposal [and general water quality management]. Firstly, water supply is a direct, overtly sought service, with few substitutes and for which top priority is accorded in allocation decisions.

Secondly, in addition to the content of effluent, the manner in which it is returned to the hydrologic system may very significantly influence subsequent use of the water and, therefore, affect the control of spillover costs. To this argument should be added the fact that the location of the site of effluent discharge also has significant influence on spillover costs and, further, that efficient quality management requires the use of collective measures on a regional scale. Collective measures of quality management are discussed later in this chapter.

Thirdly, the processes of withdrawing, distributing, and disposing of water affect the control of hydrologic subsystems, which are vital parts of hydrologic systems. Therefore, states Craine, the design and

operation of water distribution and disposal systems considerably influence water resources and the efficacy of providing high priority water services.

Craine, with considerable justification, feels that the concept of water use and waste water disposal as constituting a subsystem of water management has only recently been gaining recognition. The fragmented organizational arrangements characteristic of present day water management cannot function satisfactorily with respect to this concept. The onus is on government to intervene in the organization of regional distribution and disposal schemes. Government's objectives for so doing, he lists as twofold: (a) to make the achieving of scale economies in providing supply and disposal services a possibility, and (b) to facilitate the integration of supply and disposal services with development of the resource unit. This integrated approach to water supply and disposal, he points out, assumes greater importance in densely populated regions. While economies of scale can be obtained by merely consolidating and coordinating conventional but independent water supply and disposal services, he attaches greater importance to the fact that the utilization of some techniques are only made feasible through large scale operations.

The above regional approach should not be limited to water supply and waste disposal systems but should also extend the latter to the broader water quality management systems which are discussed later in this chapter.

Craine (20, p. 17) advocates three kinds of authorizations for the achievement of integrated regional systems. These are

> (a) authority to design, construct, and operate a regional system;
> (b) authority to acquire existing systems and to integrate their operations as indicated; and
> (c) authority to direct operations and to require interconnections and sharing of common facilities among independent systems.

The above five techniques of governmental intervention in water resources have progressional relationship in extent of responsibility and degree of intervention. This relationship is depicted by Craine in Figure 2.

The activities supporting each technique tend to become progressively more complex and sophisticated from Stage I through Stage 5. The early stages are largely devoted to influencing private and public water users and development agents by the creation of an information and/or policy environment. In Stages 4 and 5, the "intelligence" and "identification and planning" techniques may assume greater importance as inputs to "regulation," "resource development," and "regional distribution and disposal" and may even become part of a planning activity aimed at integrating these three techniques.

Government's utilization of these five techniques may be in a variety of combinations. It can choose merely to provide a policy environment

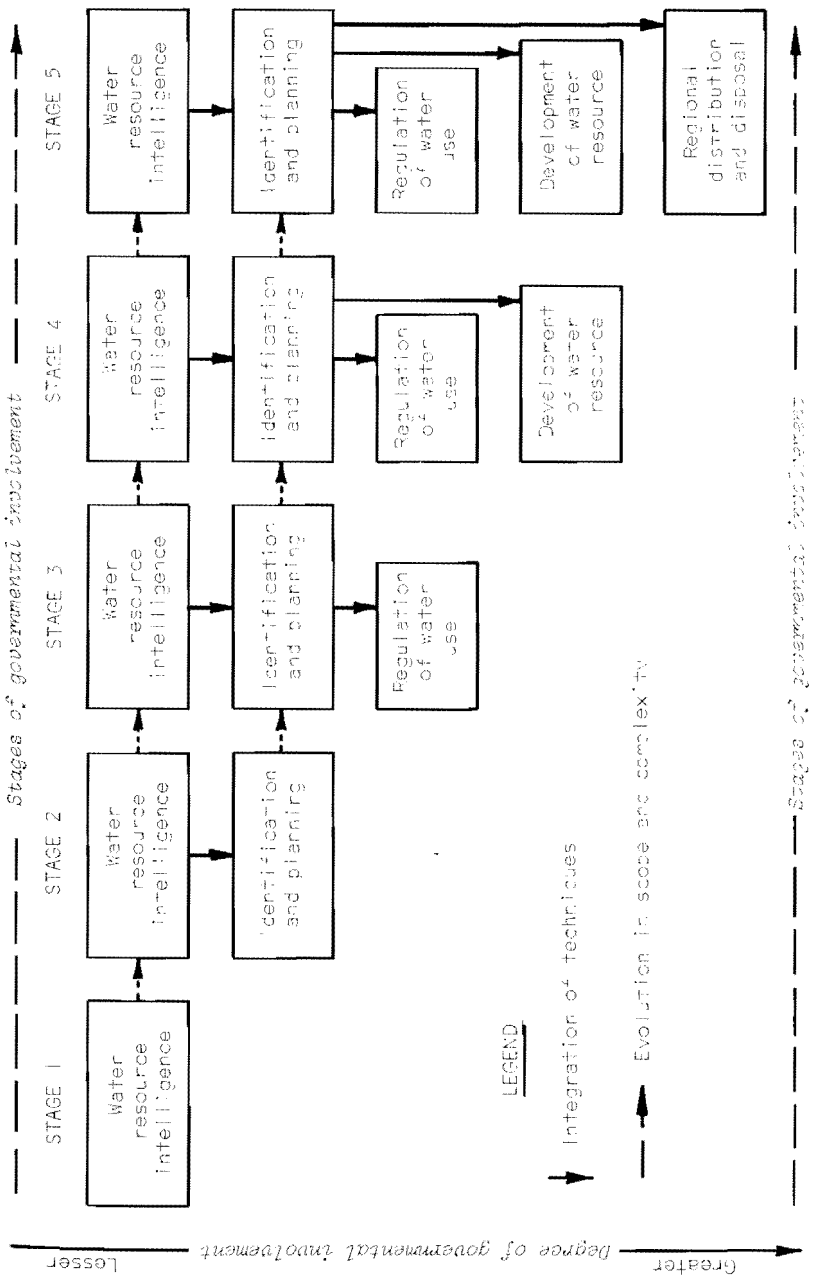


FIGURE 2. GOVERNMENTAL TECHNIQUES FOR INFLUENCING WATER USE AND DEVELOPMENT (20)

for entrepreneurs, local governments, and other agencies or, at the other extreme, it can choose to perform much of the production task directly (Stage 4) and even enter into regional schemes (Stage 5). In practice, as Craine points out, government acts through combinations of these techniques in a continuum between these extremes.

Water management he, however, describes as an advanced stage of governmental involvement, generally characterized by Stages 4 and 5. Also characteristic of the water management stage is the public utility approach with the production function very much describing [and prescribing] the dominant activities. All five techniques are essential to fully integrated water resources management which must, therefore, be characterized by Stage 5 of the above analysis.

II. WATER QUALITY MANAGEMENT

This section is intended to define what is meant by water quality management, again not so much in a single sentence or paragraph as by its content--the technical, engineering and policy measures involved. The thesis will be developed that the role of water quality management should be that of the integrator. This is seen as a much stronger role than one in which it is simply another constituent to be integrated.

While many may have written on various narrow aspects of water quality management, Kneese and Bower (1) have produced one of the most, if not the most, comprehensive analyses of water quality management as an integral part of water resources management. Their analysis is the source of much of the material in this section.

The Issues

Kneese and Bower (1, pp. 4-8) see the contemporary problem of water quality management as raising three main issues. Firstly, how is the desirable quality of water in our water courses, both surface and underground, to be determined? Concomittant with this is the degree of certainty with which the specified level [s] of quality are to be met--100 percent of the time (virtually impossible in most cases), 98 percent or some other such percentage of the time.

Secondly, what is the "best" system of management measures with which to achieve the specified pattern of quality? Here, a wide variety of alternative measures are potentially available.

Thirdly, what are the most suitable organizational arrangements for managing water quality? This includes consideration of the form and range of authority of management agencies required to make use of the alternatives provided by engineering-economic analysis and also to implement an effective and efficient management program.

These issues, it is pointed out, are related--the choice of quality level being dependent upon the cost of achieving that level which in turn is dependent upon the efficacy of management.

Based on these issues, Kneese and Bower see *water quality management* as involving "the whole range of activities from data collection, research and analysis, through operating water quality monitoring networks and treatment plants, evaluating performance of system units, setting standards and charges, and so on." These activities are depicted in Figure 3. Like Cleary, Kneese, and Banks (30, p. 4), these authors have been careful to point out that quality management embodies much more than, and is to be distinguished from *pollution control* which relies upon municipal and industrial treatment plants to curb stream degradation. The latter is but one constituent of water quality management as will be shown subsequently. Kneese and Bower have also stressed that efficient water quality management requires the explicit consideration of other outputs from water resources systems--energy, water supply, irrigation, navigation and so on.

The discussion that follows of the technical, engineering, and policy measures of water quality management in the context of integrated water resources management provides details for the definition just given and depicted in Figure 3.

Technical and Engineering Measures

Kneese and Bower (1, pp. 41-70) have discussed methods of improving the quality of water bodies. Broadly speaking, these are grouped under two main headings as shown in Table 1. They cover methods aimed at reducing waste discharges into water bodies and at increasing or making better use of the assimilative capacity of water bodies. The measures under both headings may also be combined.

The methods for reducing waste discharges are conveniently divided into those for reducing waste generation and those for reducing wastes after they have been generated. The dividing lines between these two broad groups and individual methods within them, it is pointed out, are not always as clearcut as implied in the table. Materials recovery may, for example, be considered a change in production process; in-plant water recirculation may first of all require process change; and product output changes may require production process changes. It is convenient, however, to preserve the distinctions for purposes of discussion.

The measures listed in the table and later described are oriented toward industrial plants not because municipal wastes are considered insignificant but because: (a) industrial wastes play such an important role in water quality management in the United States, accounting for the greater share of residual materials discharged to receiving waters, and requiring a complex, multi-faceted form of control; and (b) treatment is the only general method for reducing household waste discharges in the absence of significant changes in consumption patterns.

Reducing waste generation. The generation of industrial wastes, it is pointed out, is a function primarily of the type of raw materials, the production technology, the product mix, and sometimes the extent of in-plant water recirculation. It is therefore not uncustomary to find a wide range in the waste quantities generated per unit [of output] by different industries as well as by different plants within the same industry.

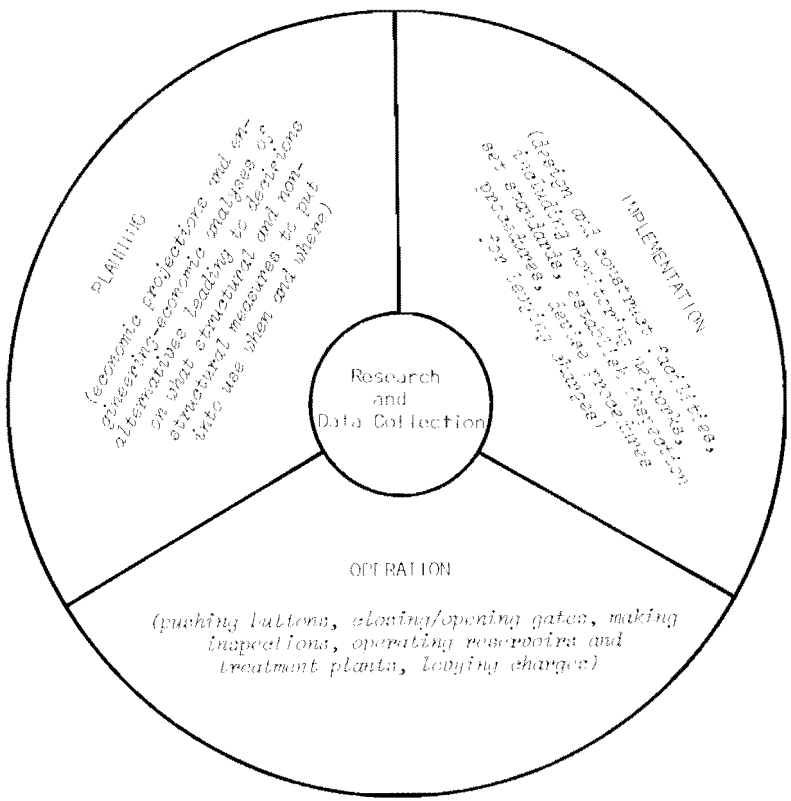


FIGURE 3. WATER QUALITY MANAGEMENT (1)

Table 1

Methods for Improving the Quality of Receiving Waters (1)

Methods for Reducing Waste Discharges
Methods for reducing wastes generation
1. Change in type of raw material inputs
2. Change in production process
3. Change in product outputs
4. In-plant recirculation of water
Methods for reducing wastes after generation
1. Materials recovery
2. By-product production
3. Waste treatment
4. Effluent reuse (including groundwater recharge, wastewater reclamation or renovation)
Methods for Increasing or Making Better Use of Assimilative Capacity
1. Addition of dilution water
2. Multiple outlets from reservoirs
3. Reservoir mixing
4. Reaeration of streams
5. Saltwater barriers
6. Effluent redistribution (including regulated discharge)

Examples of *raw material changes* that reduce waste loads are those in the type of wood used in the pulp and paper industry, and the sulfur content of crude oil used in the petroleum refining industry. In fruit and vegetable canning, factors such as the size, shape, percent of solids, and resistance to damage and bruising in harvesting and processing the raw product affect the waste load production.

The major impact on waste generation has, however, been due to *changes in production processes* brought about in most cases by other reasons unrelated to water problems, such as the economic incentive to save useful materials. In the pulp and paper industry, for example, the change from the sulfite process to the sulfate process has, by making the recovery of chemicals for reuse economic, reduced the biochemical oxygen demand (BOD) of waste loads per ton of product to about 5 or 10 percent of previous levels. Many other such striking examples are given by Kneese and Bower. The substitution of air cooling for water cooling is also cited as sometimes being a rational economic choice that will reduce the thermal waste load generated in production processes where cooling is a major component. Where stimuli have been provided, such as sewer charges, process changes have been often used as means of reducing wastes generation.

The petroleum industry has been used to demonstrate the effects of *changes in product mix or output*. The shift in this industry has been toward the production of more gasoline per barrel of crude oil input. Future changes in product mix, it is predicted, will see the production of jet-fuel increasing several fold, requiring additional use of hydro cracking with consequent changes in waste generation.

The classical change in waste load through product change has been that from hard detergents to the soft, readily degradable types. The phosphate content of these latter types of detergents has, however, continued to enrich streams and lakes and cause algal growths in them.

The beet sugar and some fruit canning industries are given as examples of industries where *in-plant water recirculation* have resulted in decreases in waste load generation expressed in BOD per ton. The difficulty of separating the effect of water recirculation from that due to changes in production processes is pointed out while stressing that water recirculation has nevertheless resulted in significantly reduced waste generation in some cases.

Reducing wastes after generation. *Materials recovery* and *by-product production* often employ similar types of processes and may, therefore, be considered a logical pair. Kneese and Bower differentiate between them on the basis of the final destination of their outputs. Materials recovery refers to the reuse of output within the same production unit as in input to the production process. By-product production, on the other hand, yields consumption goods or intermediate ones used in other production processes.

The elimination of mill scale by sedimentation and the resulting recovery of iron that can be reused in the production process is an example of waste-reducing materials recovery in the steel industry. The virtual elimination of liquid wastes in the manufacture of synthetic phenol by the use of sulfonation process together with the reported excess in the value of recovered materials over recovery costs makes it another very striking example. It is also pointed out that other examples are to be found in most major water-using or water-polluting industries.

By-product production has resulted in substantial waste load reduction in many industries. The use of waste segments of apple from the canning industry for vinegar production is one of the examples cited. The conversion of cottage cheese whey, a very troublesome waste, into protein food supplements is another example found in food processing industries.

In order to further reduce residual waste loads left after the economic processes of materials recovery, by-product production and effluent reuse have been exhausted, *waste treatment* must be undertaken. Kneese and Bower provide a list of common methods used for treating industrial wastes and also applicable to municipal wastes.

Screening	Neutralization	Incineration
Flocculation	Chemical oxidation	Biological filtration
Chemical coagulation	Chemical reduction	Activated sludge

Flotation	Wet oxidation	Anaerobic digestion
Sedimentation	Fermentation	Stabilization lagoons
Centrifuging	Emulsion breaking	Spray irrigation
Filtration	Evaporation	Disinfection
Stripping	Distillation	

Some industrial wastes may require special treatment because of color, odor, special chemicals, and toxic materials.

The above methods are based on physical, chemical, and biological processes. Some are more effective than others with respect to *degradable wastes* defined as those wastes "capable of reduction in quantity by the biological, chemical and physical characteristic of natural waters." Some are conversely more effective with respect to non-degradable wastes. Sedimentation with or without flocculation, and filtration through screens, filters, and by centrifuging are usually effective in removing the suspended solids fraction of non-degradable wastes. The dissolved solids fraction of these wastes can be removed to any desired degree, according to Kneese and Bower, by one or more of the processes of distillation, ion exchange, electrodialysis and reverse osmosis.

Organic wastes, bacteria and thermal discharges are listed as the degradable wastes of major concern. Physical processes such as sedimentation, to some degree, and chemical and biological processes such as chemical oxidation and aerobic digestion are customarily used to remove organic wastes. Biological processes and disinfection are the methods of choice for bacterial reduction while thermal loads are reduced or removed by air or water cooling systems.

It is customary to classify waste treatment into categories of *conventional waste treatment* and *advanced or tertiary waste treatment*. Conventional treatment is further subdivided into primary and secondary treatment. *Primary treatment* usually combines the physical processes of screening and sedimentation for the removal of floating and settleable suspended solids, both organic and inorganic. It achieves 25-40 percent reduction in BOD, 40-70 percent reduction in suspended solids (4, p. 235) and about 15 percent reduction of each of the nutrients, nitrogen and phosphorous (31, p. 49). The wet, and usually difficult to handle, sludge resulting from primary treatment is often digested in heated anaerobic tanks before disposal.

Secondary treatment is biological in character and, in effect, controls and accelerates the oxidation processes that occur naturally in water. The trickling filter and activated sludge techniques and their variations are the main ones used. (Descriptions of these techniques are to be found in most standard text books and thus are not repeated here). Trickling filters generally require less attention and are less susceptible to toxic substances. Activated sludge units on the other hand must be carefully controlled by skilled operators but accommodate greater operational flexibility. In combination with primary treatment, removals of the order of 80-95 percent of BOD, and 70-92 percent of suspended solids can be expected from trickling filter units (4, p. 235). The same source lists identical BOD removals for activated sludge units, with suspended solids removal for those units being of the order of 85-95 percent. Johnson

(31, p. 49) gives the percentage removal of nitrogen and phosphorous by both techniques as about 40 percent. The effluents of the combined primary-secondary treatment processes are usually disinfected with chlorine to reduce the viable bacterial count.

Stabilization ponds and spray irrigation systems are other treatment methods used to achieve comparable waste reductions to those of conventional treatment methods. These two methods are also used in the food processing and pulp and paper industries. Kneese and Bower (1, pp. 55-56) refer to an important effect of the use of these two methods, viz. that they result in an increase of the consumptive use of water per unit of raw or final product, compared with conventional treatment. In the petroleum refining industry, the increase is reported to be nearly 50 percent. Though small in absolute terms, it is pointed out that this increase may be significant during summer months when maximum water demands coincide with periods of low stream flow.

These authors also point out that stabilization ponds and extended aeration treatment methods also differ from conventional treatment methods in that their effluents contain virtually all of the plant nutrients originally in the waste discharge. These nutrients are embodied in the algae of stabilization ponds and are in mineral form in the effluents from extended aeration treatment. The effluents from these processes, therefore, fertilize receiving waters more than those from conventional treatment plants. The harvesting of fish or algae from stabilization ponds is advanced as a means of accelerating the biological treatment process, as well as extracting a major portion of the plant nutrients and some other chemicals.

Advanced waste treatment. Conventional primary-secondary treatment, as earlier stated, removes varying amount of nutrients (nitrogen and phosphorous) up to about 40 percent of the original content of municipal wastes. Weinberger (32) states that the removal of total dissolved solids by these methods is also limited to approximately 50 percent. Each municipal use of water, he further points out, generally doubles the dissolved solids content of the water. It has therefore become evident that conventional treatment is inadequate to prevent the eutrophication or overfertilization of water bodies with its adverse effects on recreational and other uses, and is also inadequate to meet the high quality demands of repeated reuse of water for municipal and industrial purposes. Considerable research has been undertaken in recent years, aimed at the development of advanced methods of waste treatment. These methods are directed primarily towards the removal of nitrogen and phosphorous and the demineralization of water. Weinberger (32; 33) and the Federal Water Pollution Control Administration (34) have discussed and summarized the research findings from the use of these methods.

Weinberger (32) lists two general types of water renovation systems: (a) the series, and (b) the parallel. The series system, he states, generally consists of treatment of the primary-secondary effluent in four steps in series: coagulation - sedimentation - filtration for the removal of suspended solids and colloids; activated carbon adsorption to remove residual dissolved organic substances; electrodialysis for demineralization; and then chlorine disinfection.

In the parallel water renovation system, the primary-secondary effluent is divided into halves. One half is passed through the coagulation-sedimentation and carbon adsorption steps while the other half is passed through an evaporation step which demineralizes or distills the flow, and an adsorption polishing step. The two halves of the flow are then recombined and chlorinated.

Cohen (34, pp. 3.41-3.52) lists and discusses the use of two other methods, reverse osmosis and ion exchange, in addition to electrodialysis for the demineralization of waste waters. While ion exchange and the other advanced treatment methods so far mentioned have been used in the past in municipal drinking water treatment plants (few of them in waste treatment plants) and are generally understood, brief discussion of the operating principles of electrodialysis and reverse osmosis may be appropriate here.

In *electrodialysis*, an electric voltage is impressed across electrodes in a cell containing the mineralized water. This causes the positively charged ions (cations) to migrate to the negative electrode and the negatively charged ions (anions) to migrate to the positive electrode. By placing cation and anion-permeable membranes alternately between the electrodes, alternate compartments become more concentrated in salts while the intervening compartments become more dilute. The water in these latter compartments constitutes the finished product.

Reverse osmosis, as the name implies, is the opposite to normal osmosis. In normal osmosis, flow takes place from the more dilute of two solutions separated by a semi-permeable membrane to the concentrated one. Reverse osmosis uses a pressure, in excess of the osmotic pressure, applied to the concentrated side to cause the reversal of normal flow, i.e., from the concentrated to the dilute side of the membrane.

Barth (34, pp. 2.16-2.19) discusses treatment for the removal of nitrogen together with phosphorous from waste waters. He points out that chemical approaches for the removal of nitrogen are limited because most nitrogen compounds in waste water are soluble. Biological denitrification aided by additions of methanol seem to be the most promising method. Other methods include combined pH adjustment and air stripping of ammonia, reverse osmosis, and ion exchange.

Phosphorous removal methods discussed by Brenner (34, pp. 1.9-1.18) include chemical precipitation with lime, iron, or alum and combined chemical-biological interactions in which iron or aluminum salts are added directly to activated sludge aerators. Electrodialysis, reverse osmosis and ion exchange also effectively remove phosphorous.

Advanced waste treatment measures must be followed by disposal processes for sludges and waste concentrates. Disposal techniques being investigated, according to Weinberger (32), include incineration, digestion, wet oxidation, disposal at sea or remote dump sites, deep-well injection, and beneficial use as soil conditioners, fertilizers, or chemical raw material.

Weinberger (32) believes it is possible to achieve any degree of waste treatment desired and at least to restore waste water to the quality of the water before use. He cites the Santee Waste Reclamation Project as pioneering the direct reuse of reclaimed municipal waste water for recreational purposes such as body contact sports and fishing.

Effluent reuse is the final method of wastes reduction discussed by Kneese and Bower (1). They point out that this method involves the reuse of municipal or industrial effluents by others than those generating the wastes. This distinguishes the method from that of effluent recirculation, described earlier, in which the reuse is by those generating the wastes.

Kneese and Bower cite Stone and Merrell (35) and Terry (36) to show that sewage effluents are used for various purposes by industries in the southwestern United States. This practice, they indicate, is less common in the east though the Sparrows Point plant of Bethlehem Steel uses effluent from the Baltimore treatment plant primarily for cooling water in steel production. The use of sewage effluents for irrigation is much more commonplace and many cities including Fresno and San Bernardino in California, Tucson in Arizona, and over 200 towns in Texas are listed as examples where this practice occurs.

Artificial ground-water recharge is another method of effluent reuse. Intermediate preparatory processes are generally needed before introduction of effluents to ground-water basins through injection wells or spreading grounds. Where spreading grounds are used, natural purification processes in soils, such as bacterial action, filtration, adsorption, and others, improve the quality of the water before it reaches the aquifer. Caution is recommended in the use of waste effluents for ground-water recharge since it may result in an increase of the total dissolved solids and the contamination of ground-water sources.

Increasing assimilative capacity. The *addition of dilution water* readily suggests itself as an attractive means of improving waste assimilation in streams because of the fact that lowest stream flows usually coincide with the worst concentrations of most water quality variables. The most common practice for augmenting stream flow, according to Kneese and Bower (1, p. 62), is by the controlled release of water from reservoir storage though it is also possible to use ground water for this purpose. They cite the interesting example of water withdrawn from Lake Erie being finally used for maintaining a minimum flow in the Buffalo River after earlier use as cooling water in five industrial concerns. Flow augmentation, it is pointed out, has been recommended by the U.S. Army Corps of Engineers for use in many river basins in the east, including the Potomac River Basin, and is likely to play a large role in future water resources management in the United States.

The effects of flow augmentation, however, may be favorable or unfavorable (37). While bacteriological quality may be stabilized and summer reservoir releases may be cooler than normal stream flows, the low oxygen content of releases from the deeper parts of stratified reservoirs may increase the costs of achieving desired water quality. The use of multiple outlets installed at different depths in a reservoir permits the combining of water from various levels to achieve a suitable water

quality. It is advanced as one of many methods of coping with the unfavorable effects of flow augmentation from storage reservoirs. Where there are power installations, air or oxygen can be introduced into water in the turbines by the use of vacuum breakers or other means.

The quality of the entire water mass of an impoundment or natural lake can be improved by mixing to prevent the occurrence of stratification. Reservoir design--its shape and location of inlets and outlets--and mechanical mixing are two means of achieving desired circulation patterns.

Mobile or fixed aerating devices installed in streams can also be used to provide artificial *reaeration* with either air or oxygen and thus improve the assimilative capacity. The effect, say Kneese and Bower, is analogous to that of a lengthy oxidation pond that is artificially aerated. Susag et. al (38) have estimated that it would be at least half as costly to use mechanical surface aeration than advanced waste treatment to maintain a minimum dissolved oxygen level of 2 mg/l in the Mississippi River immediately downstream of Minneapolis and St. Paul.

Effluent redistribution by means of regulated discharges, changes in discharge locations, and underground disposal is another method proposed for making more efficient use of available assimilation capacity. Wastes may be stored during ebb tides for release into estuaries during flood tides. Food industries use seasonal storage periods to effect some degradation of wastes prior to later discharge. The efficient use of regulated discharges requires a good data collection system that provides continuous information on the quantity and quality of both the wastes and the receiving waters.

Waste transferrals are usually made from areas of low assimilative capacity to one or more areas of greater capacity such as tidal estuaries or oceans. Borges of the Delaware River Basin Commission (DRBC), in a personal interview during April, 1969, indicated that the Commission was planning two such projects for transferrals of wastes out of the upper Delaware estuary into the lower estuary and bay.

Deep-well underground disposal of wastes has been used largely by the chemical, petrochemical and paper industries for wastes that are difficult or very expensive to treat. This form of disposal, Kneese and Bower point out, represents a consumptive use of water since the effluents are not available for reuse.

Collective measures and scale economies. The existence of economies of scale is an important consideration in connection with all measures of handling wastes (1). Costs of handling waste pickle liquor containing 8.5 percent free acid by the Blaw-Knox Ruthner sulfuric acid recovery process were reduced from about 3.5 cents per gallon to about 3 mills per gallon by processing 160,000 instead of 30,000 gallons per day. Similarly, the costs for handling wastes from fruit and vegetable canneries in lagoons and/or spray irrigation systems were reduced from 30 cents to 2 cents per pound of BOD by increasing the seasonal operation capacity from 100,000 to 500,000 pounds of BOD. The United States Public Health Service also claimed similar economies of scale for municipal waste treatment plants (1). Considerable savings could be effected in

densely developed areas by the use of collective instead of separate facilities for each municipality and industrial plant.

A regional agency has a wide variety of collective measures to choose from (1, p. 183). These include: increasing stream flows during low-flow periods by releases from reservoirs and ground-water storage; regional treatment plants for intake water, municipal and industrial wastes in compactly developed areas; artificial or induced oxygenation of watercourses; effluent diversions; specialized stream use; artificial recharge of waste waters to ground-water aquifers for quality improvement; and the construction of shallow oxidation reservoirs in streams. These measures should be used to supplement waste handling measures at individual points. They are very important alternatives worthy of the fullest consideration in water quality management.

System operation. It is not sufficient for a water resources management agency to have a wide variety of measures, such as those described above, at its disposal. The agency must be in a position to use those measures and all units in an entire system in an integrated manner so as to produce a specified time pattern of water and water-related goods and services, including water quality, at specified locations.

To operate a system in the above manner, state Kneese and Bower (1, p. 67), means must be developed for determining "when to push buttons, turn valves, open and close gates, and so on for the various units involved in, and economic activities related to, a water utilization system." They see a communications-control network involving collection, transmission, analysis and interpretation of data, signaling and response as being a necessity. Figure 4 is their schematic representation of such a network. Included in data collection would be the continuous recording of precipitation, stream flow, soil moisture, volume and quality of stored water, and the continuous monitoring of various water quality parameters in waste discharges and receiving waters. The data must be transmitted from collection points to a control center for compilation, printing and/or storage. The data may be used to predict water quality at chosen points in a system if basic relationships among stream flow, waste loads, and water quality, and between stream flow and stream velocity are known. Short-term problems, such as accidental spills of toxic materials, and long-term ones such as protracted periods of low flow can be controlled with the use of information from this type of network. Field operators and water users throughout the system can respond to signals sent out of the control center by pushing buttons, turning valves, starting reaeration devices, releasing water from reservoirs, and adding chemicals to treatment processes.

Such a communications-control network as envisaged by Kneese and Bower is by no means easily developed and operated. It requires very sophisticated instrumentation and its problems are numerous. The water resource system, for instance, must first be simulated to a high degree of accuracy. Nevertheless, the net gains from nearly optimal system plans would be significant in meeting the increasing water demands of highly developed regions. The benefits from this type of operation are well documented in the power industry (1).

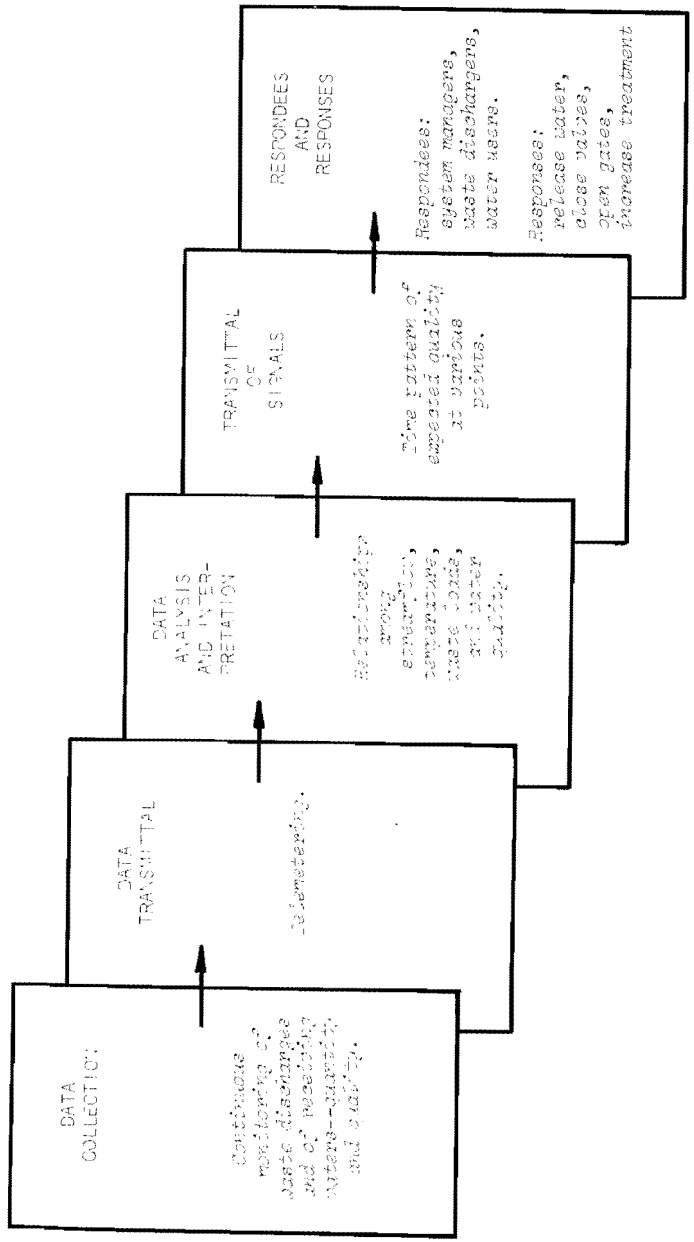


FIGURE 4. COMMUNICATIONS-CONTROL NETWORK FOR WATER QUALITY MANAGEMENT (1)

McCallum and Stierli (39) and McDermott, Ballinger, and Sayers (40) have discussed recent advances in the development of instrumentation that make it possible for water quality variables such as dissolved oxygen, temperature, turbidity, pH, total dissolved solids, conductance, and chemical oxygen demand (COD) to be continuously monitored. McDermott (41; 42) describes the pioneering efforts at continuous water quality monitoring operations on the Potomac River where dissolved oxygen, temperature and chloride have been measured. Perhaps the world's largest robot monitoring system is being operated by the Ohio River Valley Water Sanitation Commission (ORSANCO) with seventeen stations on the Ohio River and its tributaries continuously monitoring dissolved oxygen, temperature, pH, conductance, and chlorides. Monthly summaries of the information collected by the system are published (46) and used by the Commission and state agencies in assessing the effect of pollution control measures on river quality and the need for additional controls. The Commission's annual report for 1968 (44) also indicates that a staff research project has been proposed to demonstrate the application of automated forecast procedures to river quality management. A mathematical model is being developed with the aim of achieving the sort of operational control described above.

The Delaware River Basin Commission (45; 46) has already had a time-varying mathematical model developed for the simulation of dissolved oxygen variations in the Delaware estuary. The model has been used to verify past records with reasonable accuracy and, with modification, can be used for other water quality variables such as bacterial concentrations, alkalinity-pH, and chlorides. It was used during the summer drought of 1965 to forecast both the short-term and long-term effects of various flows on salinity intrusion. There are, therefore, definite indications that the technical and analytical means for implementing Kneese and Bower's proposed communications-control network are being rapidly developed.

Policy Measures

Policy considerations are very important in the decision-making processes of water quality management and are of three main types: judicial, direct regulatory, and economic. Policy should be directed towards achieving desired levels of water quality with greatest efficiency and in a manner that is most equitable to all those in any way affected by the use of the resource. Consequently, the discussion that follows will compare the various policy measures with respect to efficiency and equity. The three types of measures are not exclusive of each other and may be used in varying combinations.

Judicial measures. The earliest methods of dealing with spillover damages from waste disposal in streams has been through the use of adversary proceedings in courts of law. Under the Common Law of many States it is still possible for an individual, adversely affected by a waste discharge, to bring adversary proceedings to stop the damaging action and to be paid for the damages suffered. However, by the 19th century, according to Prakash and Morgan (47, p. 7), most States recognized the inadequacy of Common Law for dealing with the adverse effects of waste discharges and began supplementing it with some form of public regulation. These authors give the difficulties of proving the cause of

damage and the costs of court proceedings as the main contributory reasons.

Kneese and Bower (1, p. 85) see the first problem with the use of adversary proceedings as relating to the definition of damages if efficient behavior is to result from actual or potential damage claims. In the example given, a fishing firm uses resources with value of 100 units that can be transferred at no cost to other productive uses at either the same or another location, and realizes an annual return of 10 units. This firm will be willing to pay up to 10 units annually to an upstream firm to prevent it from discharging toxic wastes into the stream and so kill the fish. Should the waste discharge be such as to kill the fish, Kneese and Bower point out, the net damage done to the fishing firm is 10 and not 110 units since the 100 units of resource can be transferred and reused. It is this net damage that should be paid by the upstream firm even though the actual sale value of the fish is 110 units.

Even if damages were always considered "net," Kneese and Bower still found many deficiencies of legal remedies that would make them unlikely to produce optimal water quality programs. Six of these deficiencies are:

1. Adversary proceedings involving private parties are at best cumbersome and likely to be time consuming to the point of causing substantial inefficiencies.

2. It is almost impossible to bring suit for full damages because of the wide dispersion of damages usually associated with waste discharges into surface and ground waters.

3. It appears to be difficult to frame laws that have sufficient flexibility to meet the high variability in damage costs associated with varying hydrologic events and time pattern of waste discharges.

4. Damage from waste discharges may be dispersed over a wide area and the effects may be lasting or permanent in ground-water aquifers.

5. Legal standards applied by courts tend to be notoriously vague ("reasonable" and "substantial" being examples) and the outcome of suits are highly uncertain. These factors, combined with the substantial costs usually involved, act against the use of courts for controlling adverse effects on water quality.

6. Even if a clear right is given to either the dischargers or damaged parties and compensations arranged to reflect the value of property right, long-term adjustments in the economy will not tend toward optimality. This is because the assignment of a property right is based only on the participation in an economic activity likely to be damaged by the discharge and is not a general one exchangeable on the open market and thus tending to make water services available to the most productive user. This, Kneese and Bower (1) state, is perhaps the most fundamental deficiency.

Further limitations on adversary court proceedings have been discussed by the Committee on Pollution, National Academy of Sciences (48, pp. 231-34). These include the fact that courts are not equipped with requisite technical staffs; courts do not exercise continuing supervision over a problem shed but consider only those cases brought to them; courts generally lack authority to bring in all parties in a problem shed where such a shed exceeds the ownership boundaries of land involved in a case; and the unnecessary burden placed upon private petitioners to demonstrate special damages of a type different to those suffered by the general public.

In view of the above weaknesses or limitations, what then should be the role, if any, of the judicial process in water quality management and what changes would be necessary? The Committee on Pollution, and Kneese and Bower agree that there is a role for the judicial process even though they differ in some details of that role. The Committee expressed the view that individuals and groups of citizens should have the privilege of suing in courts for redress without first seeking the relief of public management agencies. Kneese and Bower, however, seem to disagree in recommending an essential supplementary role for the judicial process by which damaged parties can resort to court action if they feel that management agencies have not adequately considered their interests. In view of the fact that properly functioning management agencies are likely to be better equipped to consider pollution problems, to examine such problems on a comprehensive problem shed basis and to do so on a continuous basis it is felt that Kneese and Bower's approach would be more desirable and produce better results. Kneese and Bower also see the judicial process as providing some relief from damages where there are no management agencies; and also as providing a means for management agencies to enforce their directives. With these, the writers find agreement.

The writers also agree with Kneese and Bower's assessment of the Committee on Pollution's recommendations - listed below - for improving the role of the judicial process as being potentially valuable but not capable of yielding optimal water quality management. These recommendations include:

1. Establishment of an office of "Ombudsman" - a public official appointed to receive and act on private complaints. He should have authority to sue, at public expense, on behalf of complainants and this authority may be made mandatory where a specified number of persons request such intervention and show that they have been adversely affected by water quality degradation or waste discharges.

2. Designation of one or more courts in a State to process all cases in water related problems and thus, by developing specialized judges, provide better handling of technical considerations. Courts located in the same counties as water management agencies would seem to be sensible choices.

3. Simplification of the requirements for the commencement of pollution abatement actions, removing, for instance, the "special damage" requirement and authorizing the extension of the area of coverage to include all polluters in a problem shed.

4. Authorization of the appointment of water management agencies as "masters in chancery" to aid courts in the technical aspects of cases.

Kneese and Bower (1) alternatively suggest the permission of water management agencies to decide cases among contending parties - similar to the use of "administrative law" already in operation with respect to water rights in many areas. In support, they point to Wolman's reference (49, p. 100) to the absence of legal action over water rights for 50 years in British Columbia where water in streams is a public asset the beneficial use of which is not to be interfered with by prescriptive or riparian rights.

Direct regulatory measures. Direct regulation as a tool of water quality management is often based upon a set of water quality standards. Usually water quality standards are statements of minimum water characteristics to be maintained in waterways in order to accommodate designated uses. Fullest consideration should be given to all possible uses and their interactions when selecting designated uses.

Water quality standards are of two general types: (a) stream standards which establish quality requirements for receiving waters - streams, lakes, estuaries or underground; and (b) effluent standards which establish requirements for wastes discharged into receiving waters.

Stream standards are coming into general use across the United States, spurred by the Water Quality Act of 1965, Public Law 89-234. This act requires States to establish standards which "must enhance the quality" of all the Nation's interstate and coastal waters. After a number of hearings, States determine the uses to be made of particular bodies or stretches of interstate waters, set criteria required or allowed for such uses and develop specific enforcement plans to meet the criteria. The standards are subject to Federal approval.

Stream standards usually take into account dilution and assimilative capacity of streams. The establishment of criteria for these standards presents many problems. In many cases, insufficient information is available; in others optimum limits may be sufficiently elastic to require the application of considerable judgement. Many of today's standards are based on established or going practice, the origins of which are difficult to trace. McCauley (5) refers to the failure of the California State Department of Public Health to trace the origin of the 500 mg/l recommended as the upper limit for total dissolved solids in the Public Health Drinking Water Standards. Other bases for standards, states McCauley (5), include technological and economical attainability; educated guesses; experimentation; human, plant, and aquatic life exposures; and mathematical models or treatment (e.g. MPN coliforms). Attainability and the educated guess based on the best available information usually play major roles.

Sylvester and Rambow (50) discuss methodology for establishing water quality standards. Their approach combines the use of three basic principles: (a) maintenance of the original water quality - an ideal aimed at restoring water quality as near as possible to that of precivilization; (b) basing the value of each quality parameter on the requirement of the most critical use; and (c) setting requirements more restrictive than

necessary for beneficial uses in order to permit future expanded use. They recommend the establishment of water quality goals that in most cases would be much more stringent than standards and may or may not be realistic now or within the foreseeable future. These goals would serve as reference points for the comparison of standards and abatement procedures. Where and when possible, standards should be adjusted upwards toward the goals. Three ways are recommended for approximating the minimal water quality values associated with lowest flows in streams in their original or natural state prior to the advent of man. These are: (1) the examination of unaffected upstream reaches, (2) comparison with similar streams, and (3) correlation of ionic constituents with conductivity and extrapolation of a straight-line log-log plot of conductivity versus flow to the low flow value.

Both Kneese and Bower (1) and Prakash and Morgan (47) refer to the fact that stream standards, per se, represent an effective quality control measure only when there is a single effluent discharger. Maximum utilization of the stream's assimilation capacity is then possible with a high degree of flexibility. Where, however, there are many waste dischargers the application of stream standards by themselves would be very difficult, if not impossible. Under these conditions stream and effluent standards must be used in a complementary fashion. Effluent standards are meaningful only as they relate to stream standards or goals.

Effluent standards are typically of two types, those limiting the strength and/or amount of particular waste substances and those requiring uniform waste treatment. In the former case, the strength of a waste discharge may be limited to some maximum concentration in mg/l based on a dilution factor, or to an allocated number of pounds per day dictated by volume of stream flow.

In the second type, all waste dischargers may be required to adopt a uniform degree of treatment e.g. secondary treatment or its equivalent with minimum BOD reduction of 89 percent. This is essentially one of the requirements that the Federal Water Pollution Control Administration has been asking all States to adopt and which has been one of the major sources of disagreement between many States and that Federal agency.

Effluent standards are relatively simple to administer. They, however, pose problems of efficiency and equity which will be discussed later when comparing standards and effluent charges.

Prakash and Morgan (47) have described a *permit system* attributed to Busch (51). This is a form of effluent standards system based on case-by-case studies rather than uniform treatment. It is intended to avoid the inflexibility of uniform treatment effluent standards. In this system, permits of a temporary nature, subject to revision with changes in stream quality, are issued to waste dischargers. Periodic conferences between management agencies and dischargers would be used to review permits. Factors such as the cost of a higher degree of treatment, ability of other waste producers to reduce their wastes, and stream quality goals would influence permit changes.

Dales (52) proposes the expansion of Busch's permit system to make the permits transferrable through sale and purchase on the market after the marketing agency assures itself that the stream standards are not being violated. New firms would locate on sections of streams where permits are available or would have to purchase a permit or portion of one from another discharger. The system would be regulated by the management agency only to the extent necessary to assure maintenance of stream standards. Prakash and Morgan (47) see this system as possibly offering economic incentives to firms to improve waste treatment practices. Though by itself it would not assure the realization of scale economies, they feel it may encourage such action. Conceivably, it could prove more efficient and equitable than a uniform effluent standard system. Its true efficacy must, however, await its trial.

Prakash and Morgan (47) have also described the *order system* used in Wisconsin and documented by Carmichael (53). Basically there are three stages that culminate in the issuing of orders to waste dischargers. Firstly, the management agency collects detailed data on the effects of individual waste discharges on stream quality, and the type and efficiency of treatment facilities. Secondly, public hearings permit the agency to present general information on the river basin, each discharger to describe his treatment facilities and plans for improving the degree of treatment, and the public to express its opinions. Finally, the agency reviews the testimony given at the hearings and issues individual orders.

Orders usually outline control measures for particular cases of water pollution control. They might typically require minor construction and operational corrections, and the presentation of plans for new facilities. A similar system seems to be in operation in Minnesota, with respect to Reserve Mining's discharges of taconite tailings into Lake Superior. This system also seems to be the basis of the enforcement procedures being put into use by Minnesota and many other states in complying with the Water Quality Act of 1965.

While this system allows a water management agency to negotiate with waste dischargers and obtain what may be the best possible pollution reduction under the circumstances it will not necessarily lead to the "optimum" reduction as claimed by Carmichael. Experience shows that the compromises achieved generally fall short of optimal solutions.

Economic measures. "A distinctive feature of the modern problem of water quality is the fact that the economic institutions on which we customarily rely to balance costs and returns - the interaction of market forces in a private enterprise system - do not perform this function satisfactorily for waste disposal" (1, p. 3). An upstream firm or city, in planning for its waste disposal, is not forced to take into account the costs its actions impose upon downstream water users or the value of other uses of water that may be foreclosed as a result. Economists refer to such off-site damage costs and other uneconomical results of the actions of one economic unit upon another managerially independent unit as *externalities, spillover effects* or *external diseconomies.* The presence of significant externalities negates the overall tendency of free competitive markets to produce optimal resource allocations. By neglecting the downstream effects of waste disposal into watercourses, for example,

costs are understated for some economic units (upstream ones generally) and overstated for others relative to the true social (opportunity) cost that would otherwise result (1).

Kneese and Bower (1) further point out that by neglecting off-site costs, excessive amounts of waste tend to be discharged to receiving waters. Recovery of materials from, and reduction in the generation of wastes receive little attention even though studies have shown that a sizeable proportion of wastes can be "engineered away" by these techniques.

Means must be found of forcing waste dischargers to have external costs reflected in their decisions. Kneese and Bower (1) examined the possibility of establishing a market which would systematically do this. They conclude, however, that though it is possible under certain rare circumstances, the damaging effects of waste discharges may be so widespread and diffuse, and the linkages between dischargers and damaged parties so complex, particularly in highly developed areas, that a very complex and expensive procedure would be required.

These authors (1) also examined the use of a basin-wide private firm to minimize the sum of its waste reduction costs and off-site damage costs and thus "internalize the externalities." In their example a single firm owns and controls all activities on a particular river. Upstream it has a manufacturing plant that discharges wastes that are toxic to fish while downstream it owns a fishing concern. To maximize its joint profits, the firm will continue expending resources on reducing waste discharges as long as the additional incremental costs of so doing are more than offset by incremental profits or returns from fishing. Total profits will be maximized and the optimum solution reached when the incremental cost of waste reduction equals the incremental returns from fishing. Total costs to the discharger and the damaged party would also be minimized and the externalities said to be internalized. However, the use of a private decision making unit in this manner for an entire basin "would most probably result in changes in market structure (monopolization) contrary to social policy and inconsistent with efficient production because of its market power" (1). Public intervention was recommended as the necessary solution with *effluent charges* and incentive *payments* as the two types of economic measures for use in such interventions. Other economists (54; 55) have also examined and urged the use of effluent charges as a means of achieving optimal water resources allocation and efficient behaviour by waste dischargers.

An *effluent charge* is a tax imposed by a management agency upon each unit of waste discharged in a waterway such as to reflect off-site damage costs and result in optimal waste disposal.

The principle on which it is based may be briefly explained as follows (1). A charge placed on the effluent discharged by a firm can be expected to make that firm attempt to minimize its total costs (cost of waste reduction plus effluent charge) with a view to maximizing its profits. In doing so, the firm will continue reducing its waste discharges until the cost of an increment of waste reduction equals the effluent charge. This is demonstrated in Table 2 for a hypothetical firm producing

Table 2

Hypothetical Example of Effluent Charge
Minimizing Waste Disposal Costs (47)

1	2	3	4	5	6
Reduction in Units of Waste Discharged	Incremental Cost to Firm For Reduction	Total Direct Reduction or Waste Removal Cost to Firm	Effluent Charge per Unit of Waste Discharged	Total Charge (Effluent) to the Firm	Total Cost to the Firm (3 plus 5)
	(¢)	(¢)	(¢)	(¢)	(¢)
0		0	5	25	25
0 — 1	5	5	5	20	25
1 — 2	4	9	5	15	24
2 — 3	3	12	5	10	22
3 — 4	2	14	5	5	19
4 — 5	1	15	5	0	15
5		22			22

5 units of waste (47). The total cost (sum of columns 3 and 5) of waste disposal is seen in column 6 to reduce from 25 cents with no reduction in waste discharge to a minimum of 18 cents for a reduction of 5 units of waste and increase for subsequent increments of waste reduction. The incremental cost of waste reduction associated with this minimum total cost is seen in column 2 to be 4 cents or the nearest such cost to the effluent charge of 5 cents per unit of waste.

The level of the charge should be set at the marginal or incremental cost of damages resulting from the waste discharge in order to achieve the optimum solution (1). Alternatively, effluent charges can also be used to achieve stream standards in an optimum manner. The level of the charge should then be based on the marginal cost of waste reduction at all relevant points of discharge (1).

The problems of determining effluent charges are discussed in considerable detail by Kneese and Bower (1) and to a lesser extent by Prakash and Morgan (47). The functional relationship between the amount of waste discharged and the damages caused, i.e., the *damage cost function* must generally be known. In the simplest situation of the non-degradable waste, the function is linear, each additional unit of waste resulting in an equal increment of damage. Also the further upstream the discharge, the greater is the damage done since longer reaches of the stream are affected. The damage caused by degradable wastes, however, can be expected to decrease in the downstream direction as the waste is degraded. In addition, waste discharged at a critical point in a river will do more damage than if its entry occurs elsewhere. Charges would be expected to be uniform within different reaches of a river but to vary from one reach to another.

Seasonal variations in stream flow would cause seasonal variations in off-site damages and, therefore, charges should be varied to reflect these changes.

Long-run variations in damage functions due to such factors as changes in the conglomeration of industrial and other activities, and variation in reduction processes leading to variations in waste generation, treatment, and discharge should also be reflected in effluent charges.

Kneese and Bower (1) have discussed attempts at the measurement of damages caused to industrial, municipal, and aesthetic and recreational water uses by low quality water. With respect to damages to industries, they pointed out that many adjustments are possible and that as a result the problem becomes complex. With ingenuity, however, it has been possible to model and simulate effects on the petroleum, fruit and vegetable canning, thermal and beet sugar industries. These results indicated that damage costs are surprisingly insensitive to comparatively wide ranges of water quality. The sensitivity was greater to wastes of natural origin (chlorides and magnesium) than to those resulting from prior water uses and effluent discharge. Thus, they concluded, that little control of waste discharges can be justified by benefits to industrial users.

The situation with respect to municipal water supplies is somewhat similar. While poor quality intake water does impose extra costs, it is

only in the cases of toxic or evil-tasting substances were high levels of waste effluent control justified.

The evidence so far available, led Kneese and Bower to conclude that higher water quality must be justified primarily on aesthetic and recreational grounds, if it is to be justified. Damage costs with respect to these uses, however, present particularly difficult problems of measurement. In the absence of direct measurement yardsticks, indirect ones, such as the enhancement of property values, and the access costs of users who do not own or rent riparian lands, are being used to impute demand curves with respect to aesthetic and recreational damages. A study of the recreational value of water quality in the Delaware estuary (56) has showed that higher levels of dissolved oxygen might be justified on recreational grounds alone.

In view of the above difficulties, Kneese and Bower (1, p. 129) expressed the temporary need to "rely on less precise evaluation techniques [with respect to the measurement of damage functions] in our water quality management programs."

Effluent charges and collective facilities. The effluent charges policy outlined above could be applied by a regional agency which incorporates economically desirable collective measures without the introduction of any new principles (1). The capacity of a collective facility would be increased (assuming this could be done efficiently in small increments) until the marginal cost of the last increment in capacity equals the effluent charge on the waste, which in turn is equal to the marginal cost of waste control at [individual] outfalls.

If the marginal cost of increments of capacity of the collective facility is constant, the proceeds from the effluent charge would just cover the total cost of producing the capacity. If the marginal cost of succeeding increments of capacity increases, the effluent charge would produce a surplus over costs. Conversely, the effluent charge would produce a deficit if the marginal cost of increased capacity declines in the relevant range. In each case, the capacity expansion would reduce total waste disposal costs to a minimum. Since an agency incurs no costs in using the natural assimilative capacity of waterways, at least a part of the proceeds of effluent charges would be "pure rent" which could be justifiably used for artificial augmentation of assimilative capacity. Any excess revenue from effluent charges might be used for general public purposes (1).

The more or less continuous expansion of collective facilities assumed in the above theory is not realistic for small systems. There are also uncertainties in making the necessary long-run projections of population and industrial production, and their related waste discharges (1).

Prakash and Morgan (47) discussed regional collective systems and concluded that they might be financed by charges based on either average or marginal cost pricing (Kneese and Bower's effluent charge). Charges based on average costs, they pointed out, would ensure full recovery of expenditures but would not necessarily be efficient. On the other hand, effluent charges based on marginal costs would approach the least-cost

system but might result in a deficit or surplus of funds. They further emphasized that the combined use of effluent charges and collective facilities would always be more efficient than the use of such charges applied to decentralized treatment methods of individual waste producers.

Payments made to waste dischargers at the same rates as required for effluent charges would have the same result as an optimal charges scheme according to Kneese and Bower (1). Others (57; 58; 59) have disputed this claim. In any case, Kneese and Bower pointed to many administrative difficulties pertaining to information required to operate such a scheme, the necessity to pay plants that never locate in the area but which would have done so in the absence of the payment scheme, and the location, entry and exit of industry in the area. In addition, the payments technique, they state, would encourage unscrupulous operators to benefit by exaggerating their waste loads.

Fiscal incentives in spite of their much proclaimed inefficiencies are the most used economic measures for pollution abatement in the United States. Prakash and Morgan (47) grouped these incentives into four categories of tax incentives, loans, grants to industrial firms, and grants to governmental agencies for construction of industrial waste facilities.

Tax incentives of both the Federal and State types, in spite of tax savings, result in net losses to firms incurring pollution abatement expenditures. In addition, they lead to inefficient allocation of resources since the net relative prices firms face in making investments are not the same as the real cost of the resources to the society. Tax incentives, by being applied only to expenditures on equipment, discourage production process changes and other methods of waste reduction to which they do not apply (47). This last point has also been made by Kneese and Bower (1) who see tax incentives as being of little or no benefit to firms on the margin of profitability and which might have to close if effective controls are imposed. They describe tax breaks as blunt instruments, potentially costly to taxpayers and very likely to induce inefficient means of control.

Loans are subject to the same weaknesses as tax incentives but have the advantages of being useful to firms without profits; not discriminating against firms paying lower corporate taxes; and assisting firms in raising capital that might otherwise be difficult on the open market (47).

Grants to industry in the form of cost sharing programs may be subject to limitations similar to those of tax incentives. Direct grants result in lower prices than real costs to society and hence inefficient allocation of resources. Grants programs may, however, allow more flexibility, be more equitable and, if applicable to operating expenses and costs, have fewer adverse effects on efficiency than tax incentives (47).

Federal *grants to municipalities* for waste treatment facilities can be justified on several grounds but mainly with respect to domestic wastes and not necessarily industrial wastes treated in municipal plants. Such an indirect subsidy to industry, it is argued, would adversely affect waste reduction by production process changes, and charges to industry would not reflect full costs (47).

Prakash and Morgan (47) conclude that fiscal incentives are difficult to justify on efficiency grounds. When used, such programs should be aimed at fostering the use of the widest possible range of techniques and should apply to the cost of non-depreciable assets (land) as well as maintenance and operating costs. Fiscal schemes should be limited to existing industries and be continued only for a specific number of years. Current municipal grant programs should be restricted to domestic wastes with industrial charges reflecting full costs.

Comparing effluent charges and effluent standards. Of the policy measures discussed, only effluent charges and effluent standards could in theory produce economically efficient solutions (1). These two measures would have the same effect on resource allocation under ideal conditions. Differences, therefore, relate not to performance but to ease of administration, income distribution, and equity. The differences as seen by Kneese and Bower (1) are summarized below.

1. The effluent charges system requires less information whether the objective is minimization of costs associated with water quality management or obtaining the least-cost system for achieving a stream standard. With respect to the latter objective, it is stressed, the agency need not know the cost of waste reduction to each individual waste discharger, but only an estimate of the average or typical discharger's marginal costs.

2. Effluent charges offer incentive to maximum waste reduction (even in excess of required stream standards) while effluent standards provide none beyond stream standard level.

3. Effluent charges in a dynamic context, exert continuous pressure on dischargers to improve their waste handling technology. The standards system is again limited to meeting stream standards.

4. Effluent charges have the advantage of yielding revenue that may be used for financing regional collective facilities and other aspects of water resource management or for other public purposes. This is particularly attractive since it reduces the need to impose taxes to finance the provision of public goods and services.

5. Effluent charges, by making each discharger pay in proportion to the use he makes of the resource, are considered equitable. Applying the same effluent standard to all dischargers in spite of the large differences in the cost of achieving that standard is, however, of doubtful equity.

One of the few attempts at comparing the costs of achieving a given set of stream standards by means of effluent charge and effluent standard systems was made for the Delaware Estuary Study (55; 60; 61). Two effluent charge programs were considered. The Single Effluent Charge Solution (SECH) applied a single charge to all waste dischargers in the estuary. The Zone Effluent Charge Solution (ZECH) used a uniform effluent charge in each of three zones. Also considered were a Uniform Treatment Solution (UT), the same as an effluent standard approach using a uniform

degree of treatment; and a Least-Cost Linear Programming Solution (LC) which concentrated treatment at points where the critical oxygen sag could be reduced most inexpensively. Table 3 summarizes the results (55). It shows that at all levels of dissolved oxygen, but the highest, both effluent charge solutions are less costly than the uniform treatment solution. Also the zone effluent charge solution approaches the least-cost solution. The least-cost solution achieves its greater reduced costs at the expense of more detailed information on treatment costs at each point and extremely inequitable distribution of costs (1).

Table 3

Computed Costs of Achieving Selected Quality Standards in the Delaware Estuary (55)

Dissolved Oxygen Objective (ppm)	Cost of Treatment ($ Million per Year)			
	Uniform Treatment	Single Effluent Charge	Zone Effluent Charge	Least-cost Solution
2	5.0	2.4	2.4	1.6
2-3	8.4	7.7	6.3	5.8
3	11.2	7.7	7.4	6.9
3-4	20.0	12.0	8.6	7.0
4	23.0	23.0	23.0	16.0

The Federal Water Pollution Control Administration concluded, among other things, that a charge at the level of 8 to 10 cents per pound of oxygen demanding material discharged appeared to produce relatively large increases in critical dissolved oxygen levels and that such a charge was unlikely to cause major economic adjustments. The administrative costs and management difficulties of the effluent charge method though greater than for conventional methods, it was pointed out, were not insurmountable and not great enough to negate the advantages of the charge method. The charge method was also said to produce a more equitable effect on dischargers.

The effluent charge method as a tool of water quality management has much to recommend it. Support has been forthcoming from many sources during the last five years (62; 63; 64). Legislation passed by the State of Wisconsin in 1965 requested a study of effluent charges as a tool of water quality management in the State. This resulted in the study undertaken by Prakash and Morgan (47).

Despite growing interest, however, effluent charges are yet to be tried in the United States. The Delaware River Basin Commission has not attempted to implement an effluent charges system despite the favorable findings of the Federal Water Pollution Control Administration (60). Discussions with officials of the Commission in April, 1969, indicated a

reluctance to rely on effluent charges to control waste discharges directly into the estuary but that such charges would be used later for discharges to regional treatment plants that are being planned.

Prakash and Morgan (47) saw the major opposition to effluent charges coming from conservationists and industry. The former fear that charges would not be set high enough to be effective and might become "license to pollute." Industry's fear relates to paying both for treatment and waste discharge with the likelihood of higher total costs than from a regulatory system. While understanding industry's concern, Prakash and Morgan felt that the greater over-all efficiency in achieving water quality objectives ought to take precedence.

The Delaware Estuary Study, referred to earlier, has indicated that major economic readjustments are not likely to result from the use of effluent charges. Industry's added costs could be properly reflected in consumer prices. Effluent charges would ensure a more equitable distribution of those costs to all waste dischargers throughout river basins than presently used or any other known methods permit. In accord with Kneese and Bower (1) it is felt that systems of charges should be viewed as being central to regional water quality management and in turn as a component of over-all water resources management. This does not mean that other approaches should be abandoned immediately or even completely in the future. Litigation between concerned parties, and the enforcement of effluent standards should play continuing supplementary roles to systems of effluent charges.

III. ROLE OF SYSTEMS ANALYSIS

The above discussion has served to indicate the very complex nature of integrated water resources management. The decisions of management must take into consideration and reflect the rapidly growing needs of highly urbanized and industrialized populations. Choices must be made among many uses, the requirements of which pose a variety of conflicts. No longer can the effects of water use on subsequent uses and users be ignored. With demands rapidly approaching the limits of available resources in many regions multiple use has become necessary and, with it, very complex systems of water quality management. The pressures for efficient management of water resources are obviously great and increasing. No longer can decisions be based entirely upon intuition and experience. Rational planning based upon rigorous and explicitly measurable information is a necessity, as stated by Fisher (65). Fisher describes rational planning as being "truly comprehensive in its attempt to account simultaneously for as many aspects as can be related to a proposed course of action, and that accounts for both the short run and the long run." In addition, it is felt that all possible alternatives of achieving a desirable goal or objective should receive fullest consideration in decision making processes.

A relatively new and rapidly growing technology has emerged during the past decade or two to provide management with the tools necessary for decision making of the type described above. This is the area of management science commonly known as systems analysis or operations research. *Systems analysis*, as Fisher very well describes it, is "concerned with

the explicit description of the interactions between the various components of a complex situation, with precise statement of objectives sought, and with the prediction and evaluation of the consequences of taking various courses of action." The problem is usually stated in the form of a mathematical objective function that is to be optimized within one or more constraints. Systems analysis has been used with considerable success in the defense and industrial sectors, and has since been finding increasing application in the management of water resources and other aspects of the environment. The importance of this tool in water resources management has been stressed by many including the Committee on Water Resources Research of the Federal Council for Science and Technology (14) which rated it in a high priority category of needed research.

The general principles and the application of a systems approach to water resources management have been discussed by Wiener (9, pp. 99-147). He sees water resources management as being concerned with the establishment of the quickest and least expensive way for changing existing parameters of the resource into those required by the demand function, while taking into account the conservation and budgetary constraints inclusive of both the capital and human budget and their growth potential. The five basic parameters of the objective function of the management equation are (9, p. 129):

1. The space-time parameter; the three space coordinates and the time coordinate of the point at which a certain flow will occur at a certain time;
2. The quantitative parameter, expressing the cumulative quantity of water over a certain period, usually one year;
3. The flow rate parameter expressing the variability of the flow within season and cycles;
4. The mineral quality parameter, usually expressed as total dissolved salts (TDS);
5. The biological quality parameter.

While these parameters are fairly comprehensive they are by no means complete and should be expanded to include at least physical quality (temperature specifically) and radiological quality parameters in view of recently increased concern in these areas.

The parameters are interrelated, being subject to influences within the management basin and, where applicable, within a wider management context. The objective function is obtained by using a set of values and a set of functional relationships to express the status quo, as well as the inherent change trends of the parameters at the outset of development. The parameters of demand are usually expressed by a different set of values and relationships. The complete set of relationships comprising a single or several equations is then optimized within budgetary, conservation and sometimes other constraints. Quantitative and/or qualitative parameters may appear as constraints in situations where the resources are likely to become scarce. Cost parameters may appear in both the objective function and the constraints.

The ideal establishment of a single parameter for optimization, embodying in a single function both the quantitative and qualitative

aspects of a management unit is, through lack of data and hypotheses, not yet achievable. As long as this situation persists, the quantitative parameter can be optimized for a number of qualitative constraints and the most attractive pair selected for implementation (9).

In view of the wide spectrum of views that find shelter under the term "conservation" the concept preferred by Wiener (9, pp. 130-131) is worth discussion here. He supports the thesis of Morse (66) that a "changing resources spectrum" will change the "resources base" of production, and, therefore, it is not economically or even morally justifiable to insist on quantitative conservation of a resource with a view to achieving a continuous and constantly sustained yield of that resource. Morse bases his thesis on the incongruity of the 20th century view of the natural resource base and the classical conservationist notion of fixity, requiring the sustained yield type of exploitation regularly employed by engineers. He points to the fact that expanding technology has resulted in the inclusion of many items in the resource inventory that were not recognized as such 200 years ago: petroleum, ferro-alloys, aluminum, nitrogen, mineral fertilizers, and uranium to mention a few.

Morse proposes that the way for present generations to meet their moral obligations to future generations is not necessarily by sustained physical yield but instead by maintaining or increasing what he terms the "social welfare output." This term he defines as (66, p. 19):

> ... the gross output of society valued in non-economic as well as economic terms, full provision being made for the replacement of wasting assets, for research to assure an adequate continuing flow of socio-technical innovations, for maintaining the qualitative dimensions of the consumption mix, for avoiding deterioration in the esthetic qualities of the natural and man-made environment, and for avoiding deterioration in the conditions of human work.

Thus, he continues, "we may and should act on the assumption that future generations will welcome - or at least will have no legitimate cause to complain if they receive - an unimpaired per capita stock of social wealth." By this doctrine, the share of different resources in the stock transmitted to future generations will change as a result of the variability of the resources base.

Morse, after demonstrating that his thesis is applicable to both renewable and exhaustible resources, concludes that policy must be aimed at avoiding a final loss of social welfare regardless of what happens along the way and it should be framed in the positive terms of optimal resource use and not the negative ones of optimal conservation.

Wiener (9) shows that Morse's doctrine can be applied to water resources which usually are placed in the category of renewable resources. Management, in applying this doctrine, may be guided by one of the following three alternative ultimate decision patterns (9, pp. 131-132):

1. The stable equilibrium - to attain after transient stages, a new stable equilibrium, with only minor oscillations

representing short-term fluctuations;

2. The unstable equilibrium - to arrive, after transients, at an unstable equilibrium, requiring continuous intervention, in order to avoid "run-away" conditions;

3. The no-equilibrium - to reach conditions of no equilibrium, and ensuring our ability to deal with such conditions.

Each of the three has a place, he points out, in the overall spectrum of a management plan and the choice of decision patterns will depend upon evaluation of specific hydrological and socio-economic conditions and their influence on the maintenance of social wealth. Agreement is found with the argument of this approach.

Many of the early applications of systems analysis used the linear programming optimization technique to achieve steady state solutions to water resources problems. The problems of water resources management are not, however, steady state in nature but subject to continuous changes with time. Solutions are necessary in the four dimensions of space and time. Mathematical models must be developed to investigate and predict all transients between the initial and final steady states. Progress is being made in the development of such dynamic models as is evidenced by the time-varying dissolved oxygen model developed for the Delaware Estuary (46) and referred to earlier. Dynamic hydraulic performance and water quality models used in the San Francisco Bay Delta water quality control program have been described by Stann and Ringwood (67). Hall et al. (68) have applied systems analysis techniques to the planning of a complex water resources system. The literature (69) has references to other applications in a variety of areas of water resources management.

Systems analysis is a tool that is absolutely necessary for rational decision-making in the integrated management of water resources. It is rapidly growing in stature with the development of new modelling and optimizing techniques. All regional water resources management agencies should have access to it.

IV. QUALITY MANAGEMENT - THE INTEGRATOR

A number of points can be traced from the above discussions to indicate the role that water quality management should play in an integrated water resources program.

1. Quality management is central to the provision of adequate water supplies. The Committee on Water Resources Research, the Federal Council for Science and Technology (14) has recognized it as such.

2. That Committee further recognized that even in the presence of abundant water supplies, sequential use by cities and industries means that quality rather than quantity is likely to be the limiting factor.

3. It is proper quality management more than anything else that will force efficient water use.

Kneese and Bower (1) point to the fact that increasingly stringent effluent standards are making the economics of in-plant water recirculation more favorable. It is possible, they indicate, that water may be suitable for reuse within a plant, even as process water, and yet not meet required effluent standards. Such water recirculation would not be undertaken in the absence of a quality management policy that forces it. What has been said for in-plant recirculation of water can also be said for the other measures discussed that lead to the reduction of waste discharges.

4. In the regional approach to water resources management, the consideration of qualitative aspects will ensure full consideration of quantitative ones also. Where quantitative considerations are uppermost, however, downstream users may find their allocations reaching them but of quality completely unsuited to their needs.

The Mexican Treaty of 1945 which guaranteed Mexico 1.5 million acre-feet of water annually from the Colorado River is a case in point (24, p. 134). The water reaching Mexico has been high in salinity and, as a result, damaging to Mexican crops.

5. It is, therefore, quality management that is limiting in determining the extent of governmental involvement in water resources management. Comprehensive quality management would require the Stage 5 type of involvement in Craine's schematic described earlier.

6. It is quality management that will force the fullest consideration of the external or spillover effects of water use and thus lead to optimal resource allocation.

7. Comprehensive quality management of the type described will lead to optimal over-all water resources management. Likening water resources management to a jig-saw puzzle, the provision of comprehensive water quality management will, as it were, result in the other pieces of the puzzle falling into place.

The thesis is, therefore, advanced that water quality management should not merely be integrated into water resources management; rather it should be the integrator. It should be the nucleus that forces and induces the proper policies and actions in the other aspects of integrated water resources management. It is the decisions (policy and otherwise) taken with respect to water quality management that will determine the true effectiveness of water resources management.

CHAPTER 3

INSTITUTIONAL ARRANGEMENTS FOR WATER RESOURCES MANAGEMENT

The analysis of water resources management outlined in the previous chapter is used to develop a set of suggested criteria with which to develop and assess institutional arrangements for water resources management. In the context of the United States, the roles to be played by governmental and private institutions, federal, state and local are examined. Major problems to be faced in integrated water resources management are also discussed.

1. CRITERIA FOR WATER RESOURCES MANAGEMENT INSTITUTIONS

In the course of his analysis of the five important characteristics of water resources and the five stages of governmental involvement described in the previous chapter, Grains (20) has suggested and discussed six criteria for evaluating water management institutions. Though he refers to them as guidelines, it is felt that they should be considered as essential rather than rigorous criteria. They are as follows:

1. Ability to apply the total range of governmental techniques for influencing water use and development.
2. Ability to consider and adjust (or adapt to) externalities stemming from hydrologic interdependencies.
3. Flexibility to adapt water management actions to different circumstances of time and place with protection against arbitrary and capricious actions.
4. Ability to express and consider the range of values relevant to a water management decision.
5. Ability to finance water management consistent with its objective of efficiency.
6. The extent to which water management is recognized and established as a governmental as a continuing function.

We propose to describe these in more detail thus:

Ability to apply the Total Range of Governmental Techniques for Influencing Water Use and Development

The basis for this criterion relates to the extent to which the institutional framework between legally authorized and otherwise geared to operate at various levels of Grains's schematic of governmental involvement described in Chapter 2. The institutional system should have the legal powers and practically be conducted each of the five specific activities, viz. intelligence, identification and planning, regulation of water use, development of water resources, and regional distribution and disposal. The question of the appropriateness and adequacy of the authorization arises as does that of a unified command for the administration of the system. Effective administration of water management, he points out, can hardly be expected the with dispersed responsibilities for applying the techniques listed above.

Ability to Consider and Adjust (or Adapt to) Externalities Stemming from Hydrologic Interdependencies

The major concern of this criterion is the ability to adjust to externalities that might otherwise result in inefficiencies under fragmented responsibilities.

This criterion can be satisfied in essentially two ways. One, place the water management activities of a single hydrologic unit under a single organization and thus institutionally internalize the externalities. Two, provide legal and administrative requirements for the exchange of payments among water use and development agencies in accordance with spill-over damage or beneficial effects.

Flexibility to Adapt Water Management Actions to Different Circumstances of Time and Place with Protection Against Arbitrary and Capricious Actions

Three considerations arise here: (a) the legally provided degree of administrative discretion; (b) the extent to which administrative goals, policies and standards constrain specific decisions; and (c) the extent to which decisions can be reconsidered and adjusted over time. It is important that a balance be maintained between flexibility and stability. Adequate security should be provided to independent entrepreneurs and development agencies without creating conditions that may restrict shifts in patterns of resource use.

Ability to Express and Consider the Range of Values Relevant to a Water Management Decision

This criterion is concerned with the problem of finding means to express the range of values associated with the regional disconformities (among the hydrologic, demand, and government systems) in water management decisions. Six institutional features that may contribute to satisfying this criterion are:

1. The jurisdiction of the water management agency may be made wide enough to include many of the hydrologic, demand, and governmental systems. This may be difficult to achieve in complex situations.

2. Values amenable to monetary expression may be articulated by pricing and inter-system transfer payments.

3. Formal interagency review procedures may be used to link non-monetary values finding expression in the decision process.

4. Representation on governmental boards may be such as to assure the participation of all relevant interests.

5. Decision making rules may be framed to assure the consideration of important values.

6. Requirements for consultations and provisions for appeals and hearings may further assure the participation of individuals and interest groups.

Ability to Finance Water Management Consistent with its Objective of Efficiency

Two considerations are identified as being relevant to the financial ability of an institutional system, viz.: (a) the existence of unusual obstacles to raising capital and operating funds; and (b) the extent to which disconformities in the incidence of costs and benefits encourage inefficiencies.

This criterion is considered to be of very great importance in view of the inability of many existing agencies to function as intended because of inadequate financial arrangements.

The Extent to which Water Management is Recognized and Built into Government as a Continuing Function

Ad hoc arrangements are viewed with searching skepticism particularly when such arrangements do not lead to permanent legal and administrative measures that employ the five basic governmental techniques for directing water use and management. Other considerations include the provision of procedures for relating water management decisions to other relevant governmental policies and operations.

As in his consideration of the important characteristics of water resources (see Chapter 2), Craine has failed to make specific reference to the very important environmental interdependencies and interrelationships. While under his last criterion he does point to the need to relate water management decisions to other relevant governmental policies and operations, this reference is insufficient to ensure the proper consideration of environmental interrelationships when planning and evaluating institutional arrangements. As a matter of fact, Craine's evaluation of the institutional arrangements in England and Wales (20) has not examined the provisions, if any, for ensuring that environmental interdependencies and interrelationships are adequately taken into account. Accordingly, the writers propose to add a seventh criterion, as described below, to Craine's six.

Ability to Account for Environmental Interrelationships

Two considerations are of importance here: (a) provisions for integrating water resources and related land use management; and (b) accounting for the interrelationships between water and other activities having impacts on environmental quality.

The satisfaction of this criterion does not necessarily require the establishment of a single agency with jurisdiction over water resources, land use management and other aspects of environmental quality. It should be sufficient to provide explicit and formal channels of communication among responsible agencies.

Criteria for regional water quality management agencies have been discussed by Kneese and Bower (1, pp. 303-308). These and their basic determinants are reproduced in Table 4. Examination of this table indicates that Kneese and Bower's criteria are included in the more compre-

Table 4

Determinants and Criteria for Regional Water Quality Management Agencies (1)

Determinants	Criteria
Existence of externalities.	Regional agency should be able to internalize the major externalities associated with waste discharges.
Economics of scale in various measures to handle wastes and to improve assimilative capacity of watercourses.	Regional agency should be able to implement measures of all types to improve water quality.
Inseparability of water quality from water quantity, interrelationships between water quality management and other outputs from water systems.	Regional agency should be able to take adequate account of the interrelationships between water quality and other aspects of water systems.
Interrelationship between spatial location of economic activities and water quality management.	Regional agency should be able to take into account through specific communication channels the interrelationship between water quality management and land use management.
Interrelationships between water quality management and impacts on other aspects of environmental quality, i.e., air, solid wastes disposal.	Regional agency should be able to take into account through specific communication channels the interrelationships between water and other activities having impacts on environmental quality.
Many of the benefits and costs associated with water quality are difficult to quantify in a generally acceptable manner.	Regional agency should: (a) delineate the wide range of choice possible--costs and consequences of different combinations of measures and of different levels of quality; (b) reflect or consider adequately the views of those affected by water quality management activites.

hensive set of seven criteria earlier adopted.

II. ROLES OF GOVERNMENTS OF GENERAL JURISDICTION

The need for governmental intervention in water resources affairs has been demonstrated and the techniques available to governments for effecting water resources management have been discussed. A set of institutional criteria for the integrated management of water resources has also been proposed. It now remains to consider the roles to be played by each of the three levels of government, Federal, State, and local, that are characteristic of the United States.

Craine (70, pp. 10-13) has briefly traced the changing role of governmental involvement in water resources use and development in the United States. The spirit of "laissez-faire" dominated water development by the early settlers. Later the establishment of water rights by States provided the legal framework within which a "laissez-faire" system of development was continued. This system gradually became limited as various kinds of regulatory law were used to give direction to water development. States used their constitutional "police power" to pass regulations aimed at protecting the health, safety and general welfare of their citizens. These regulations related primarily to pollution control and the withdrawal of water from natural sources.

The Federal Government, exercising its authority over navigable waters and the management of public lands, international relations, and interstate affairs, imposed both direct and indirect regulatory controls. Further, when by the middle of the nineteenth century private entrepreneurs and local governments needed help in developing water sources, the Federal Government responded more readily than States and has since maintained this lead. The Federal Government, using its vast resources to advantage, has organized navigation, irrigation, flood control and hydroelectric projects on a scale beyond the capabilities of private enterprise and smaller governmental units. Recent years have seen the Federal Government, by means of the Water Quality Act of 1965, extending its programs into the pollution abatement area, one of the traditionally primary domains of state and local governments. By means of the Water Resources Planning Act of 1965, the Federal Government has also assumed the lead in promoting comprehensive river basin planning and the establishment of river basin commissions.

The implementation of integrated water resources management as earlier described will require much greater direct involvement by State governments. These governments must assume dominant roles not only in the regulatory aspects but also the development and operational aspects of water resources management. As Craine (70) states, choices must be made which will have deep economic-political overtones for States as sovereign entities. He also points to the urgent need for new intergovernmental relations. Let us now examine the roles that should be played by the three levels of government.

Federal Government

The Senate Select Committee on National Water Resources [illegible] the following recommendations in 1961 as to the Federal Government's role in this area.

1. The Federal Government, in cooperation with the States, should undertake the preparation and periodic updating of comprehensive water development and management plans for all major river basins in the United States.

2. The Federal Government, by means of grants, [illegible] States into greater planning, development and management [illegible]

3. The Federal Government should undertake a broader [illegible] research program on water, expanding and providing better balance [illegible] its programs of basic and applied research.

4. The Federal Government should prepare biennial [illegible] water supply-demand outlook for each of the nation's water resource regions.

5. The Federal Government in cooperation with the States should take a variety of steps to encourage efficient water development.

The American Water Works Association (71) in its policy statement sees the Federal Government's role as being "supportive and cooperative, not preemptive." It should provide:

1. Continuing cooperation with States and local, private and public agencies in planning for unified development and management of river basins.

2. Systematic and effective coordination among Federal agencies concerned with water resources activities.

3. Research of the type beyond the capabilities of State and local groups and closely coordinated with the efforts of the [illegible] possible.

This association also outlines a number of principles to be recognized by the Federal Government. These include encouraging the establishment of [interstate] compacts; encouraging State and local agencies to assume greater responsibilities for all aspects of water resources management; and the right of each State to control the use of its water and related land resources within clearly defined national needs and interstate responsibilities. The Federal Government, it is pointed out, should only assume the initiative in development when the magnitude of a project is beyond the capacity of local groups; no local or State groups can be clearly identified as principal beneficiaries; maximum feasible development within a comprehensive regional or basin plan requires it; or programs and projects do not compete with alternative means of development by State and local initiative.

Kneese and Bower (1) see water quality management [in the context of over-all water resources management] as being largely the province of State and local governments with federal leadership playing an important role in dealing with interstate waters. Accordingly, they point out, the Federal Government may directly establish regional agencies such as the TVA though this is not a great likelihood, or it may provide guidelines and incentives for the establishment of intrastate and interstate regional agencies for water quality or total water resources management. With such agencies established, the continuing role of the Federal Government should be:

1. To intervene in terms of data collection, analysis and enforcement in the absence of a duly constituted organization or State action.

2. To maintain "headquarters" teams of planners to aid regional and State agencies in their continuing planning and implementing functions.

3. To expand its network of quality monitoring stations and so provide the base network data against which to compare data from short-run sampling stations.

4. To maintain a strong program of research on various aspects of management and make the results available to State and local agencies.

This study recommends the following role for the Federal Government:

1. The establishment and maintenance of a clearly defined national policy on water resources management to serve as a guide and framework within which States may operate. This is in keeping with the Federal Government's responsibility for the welfare of the nation as a whole.

2. The provision of guidelines and incentives for States to establish and operate intrastate and interstate regional agencies with full authority to undertake water resources management as described in Chapter 2. The Federal Government may very usefully and effectively lead the way to introducing some of the new techniques and concepts, such as effluent charges, that are important constituents of integrated water resources management.

3. The provision of supplementary funding of State and local management agencies to permit the fullest execution of all aspects of their programs, planning through construction and operation.

4. The joint undertaking with States of the preparation and periodic updating of comprehensive water development and management plans for all major river basins.

5. The expansion of its network monitoring stations of all types (quality, hydrologic, etc.) to provide basic background information against which to compare data from short-range stations. Such network monitoring stations may also be linked with those of regional agencies to provide information on which day-to-day management decisions can be made.

6. The provision of such other services, data collection and processing, periodic studies, and enforcement of regulations that cannot or are not undertaken by State agencies. Mediation services may also be provided for the settlement of disputes, particularly those with interstate repercussions.

7. The provision of joint representation with States on international commissions and for other activities pertaining to international boundary waters.

8. The maintenance of a strong program of basic and applied research, the results of which are made available to State and local agencies. Such a program should be coordinated with those of State and local agencies to ensure that each level of government and other agencies are undertaking the type of research to which they are best suited, and also to avoid unnecessary duplication. Advanced waste treatment, systems analysis, the definition of water quality damage functions, analytical methods for water quality determination, and the effects of synthetic and other chemicals on the aquatic environment are some of the areas requiring greater attention.

9. The expansion of its various training programs, courses, seminars, etc. to help States provide the increasing number of qualified staff members required for their programs. This would include increased financing of graduate students and research programs at universities.

State Governments

Kneese and Bower (1) proposed the following role for State Governments:

1. Facilitating the organization of adequately financed regional management agencies of appropriate size and authority within their areas of jurisdiction. In doing so, State governments would assume primary responsibility for seeing that the criteria relating to such agencies are met.

2. Providing technical advice and possible financial aid to regional agencies as proposed for the Federal Government vis-a-vis the States.

3. Conducting appropriate management programs in areas lacking the size and development to justify a regional agency.

This study recommends the following role for State Governments:

1. Active promotion of the establishment of regional agencies of appropriate size and authority, and meeting the criteria proposed earlier in the chapter. Where interstate agencies are considered appropriate, States should work towards their early establishment, the same criteria being applicable.

Associated with this would be the reorganization of State agencies to reflect the abolishment and phasing out of departments, commissions, etc. made redundant by the establishment of regional water management

agencies. The staffs, facilities, etc., of some of these existing State agencies should be used as the nuclei of the new regional agencies.

2. Provision of the broad policy within which the regional agencies will operate.

3. Establishment of clear lines of authority from State governments through regional agencies and local governments and agencies.

4. Promotion of the reorganization of local agencies in the interest of efficiency. This may involve the amalgamation and abolishment of existing agencies and the creation of new ones.

5. Provision of technical advice, services, and financial aid to regional agencies as required. This may include management programs in small areas on behalf of regional agencies.

Local Governments

Kneese and Bower (1) considering the role of local governments with respect mainly to water quality management, stress the responsibility of these governments for land use management and the effect of such management on water quality management. They also see these governments as playing important roles in the management of environmental quality problems, including water quality, and in the management of their water supply and waste disposal facilities.

This study recommends the following role for local governments:

1. Active representation, not necessarily by elected members, on governing boards and councils of regional water management agencies to provide local input to decision making and liaison between regional agencies and local governments.

2. Management of their water supply, waste disposal and other water related facilities such as to meet the requirements of, and in close coordination with, the regional water management agencies.

3. Close coordination and integration of the activities of their agencies together with the close coordination of these activities with those of the regional water management agencies.

4. The provision of water management services, at local levels, best handled by them on behalf of the regional water management agencies.

III. INSTITUTIONAL AND ORGANIZATIONAL APPROACHES

A study of the approaches of others to the solution of similar problems can always be instructive and fruitful, particularly if addressed to the underlying concepts and principles involved. Such studies help in pin-pointing some of the alternative methods of achieving the same ends, and the relative weaknesses and strengths of these alternatives. It is with this in mind that this section examines a number of approaches to integrated water resources management used both abroad and within the

United States.

The Genossenschaften of the Ruhr

The eight large water resources associations, generally referred to as the Genossenschaften, operating in the Ruhr industrial area of West Germany perhaps provide the world's first examples of water quality management in the context of total water resources management. The description that follows is based mainly on that of Kneese and Bower (1). Other English language descriptions are given by Kneese (72) and Fair (73) while Kneese and Bower (1) list many other relevant references written in the German language.

The Ruhr area shown in Figure 5 contains 40 percent of the industrial capacity and 70 to 90 percent of the production of coal, coke, iron, and steel in West Germany. Its 4,300 square miles containing some 10 million people rank it as one of the world's most concentrated industrial areas.

Problems of land subsidence in the flat Emscher Valley due to coal mining, and epidemics stemming from severe flooding of the highly polluted river reached crisis proportions at the turn of the century and led to the establishment in 1904 of the Emschergenossenschaft, the first of the eight water management associations. The success of this one led to the formation of six others by 1960 and the last one in 1958.

These associations have done a remarkable job in managing the rather limited water resources of the region to meet its great needs. The five small rivers, Ruhr, Lippe, Wupper, Emscher and Niers, with a combined annual average low flow of only about one-fourth that of the Delaware River near Trenton, New Jersey constitute the water supply and the water-bourne waste carriage and assimilative capacity of the area. The Rhine River into which these five flow is used more for its waste carriage capacity than for water supply. The magnitude of the problem faced by the Genossenschaften is demonstrated by the fact, according to Kneese and Bower (1) that the annual average natural flow in the Ruhr is less than the volume of the effluent discharged into it. Despite this, management has been so successful that this stream is used for household and industrial water supply and recreation. Indeed, the Genossenschaften have generally made a small supply of water meet the needs of the mines, factories, and households of the Ruhr's massive industrial complex while also permitting the use of streams for recreation and waste disposal. This has been achieved at relatively modest cost (1).

Much of this success is attributed to the institutional arrangements which permitted the Genossenschaften to plan and operate a relatively efficient regional system based on the use of a wide range of alternatives. These associations achieved the major benefits of formal optimization procedures without actually using them by viewing the problem of water supply and waste disposal as one of integrated system planning and design. They integrated land use management by cooperating with the responsible association in the area. They have made considerable use of collective facilities where scale economies have been indicated, even to the extent of linking the entire Emscher watershed to a single treatment plant. They have used stream specialization, the Emscher's entire flow being used for

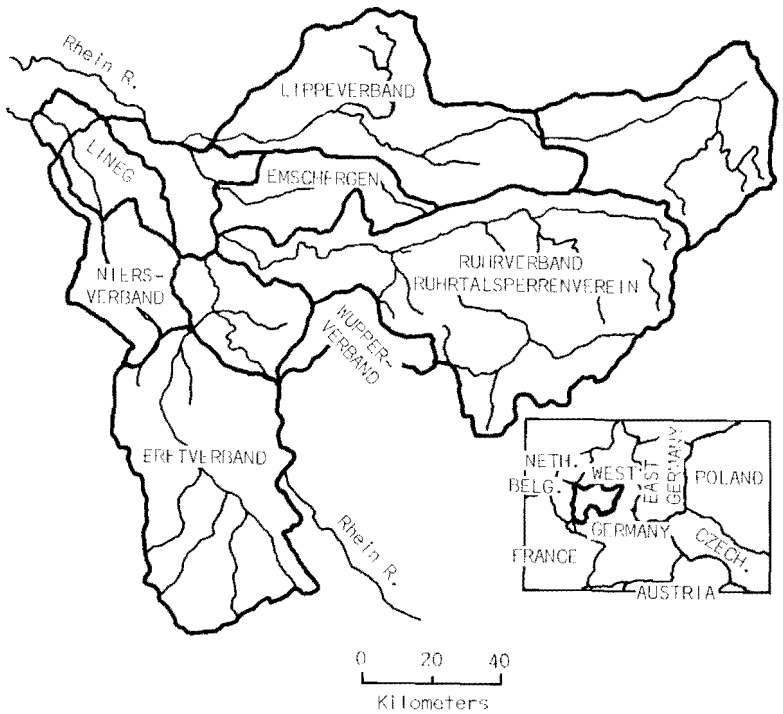


FIGURE 5. RIVER BASINS OF THE RUHR DISTRICT (1)

waste dilution, and a variety of other quality management techniques including low flow augmentation, stream aeration, and materials recovery.

The Genossenschaften have induced process changes by the levying of effluent charges. A detailed description of the formulas used in determining their effluent charges is given by Kneese and Bower (1). These charges are based on both quantity and strength of waste discharges. Fee systems are also operated for water supply, flood damage reduction, recreation, and hydroelectric power. They have built and operated their own materials recovery plants, central stations for the detoxification of industrial sludges, pumping stations, trunk sewers, run-of-the-river power plants, flow regulating dams and electrical distribution systems. By using a single staff for planning, building, operating, and supervising the facilities of a single basin, they have effected substantial economies. A description of the institutional arrangements that facilitate such a comprehensive program involving such a wide variety of alternatives now follows.

Organizational Arrangements. Kneese and Bower (1), pointing to the similarity among the Genossenschaften, describe the organizational arrangements of the Ruhrverband-Ruhrtalsperrenverein as being representative of the others. The Ruhrverband was formed in 1913 with water quality regulatory powers and to support the water supply functions of the existing Ruhrtalsperrenverein (Ruhr Reservoir Association). The two organizations with separate boards of directors have been operating under a single managing director and using a single staff as shown in Figure 6 since 1939.

The seat of political power is the governing board made up of: (a) the owners of business, industrial and other facilities in the area that contribute to water quality deterioration of the Ruhr and its tributaries, and those who benefit from the activities of the Ruhrverband; (b) communities within the management region; and (c) the Ruhrtalsperrenverein, representing the waterworks and other water withdrawal facilities.

The assemblies and boards of directors constitute the political organs. The assembly members (about 1500) elect the board of directors and approve all management decisions including the assessment of charges on an absolute majority basis. Each member casts a number of votes in proportion to the financial contribution he represents.

The Board of Directors of the Ruhrverband, consisting of a Chairman, his deputy, and seven additional members, are all elected by the assembly from among its membership. All three of the categories of membership listed above must be represented on the Board. Being only part-time employees and not necessarily skilled in water resource matters, the Board members appoint a staff director to manage the program. The staff of some 850 persons includes about 400 professionals.

The Genossenschaften from the above description may be likened to cooperatives in the Anglo-American sense but with membership being compulsory and voting power related to the extent of financial contribution to an association's expenses.

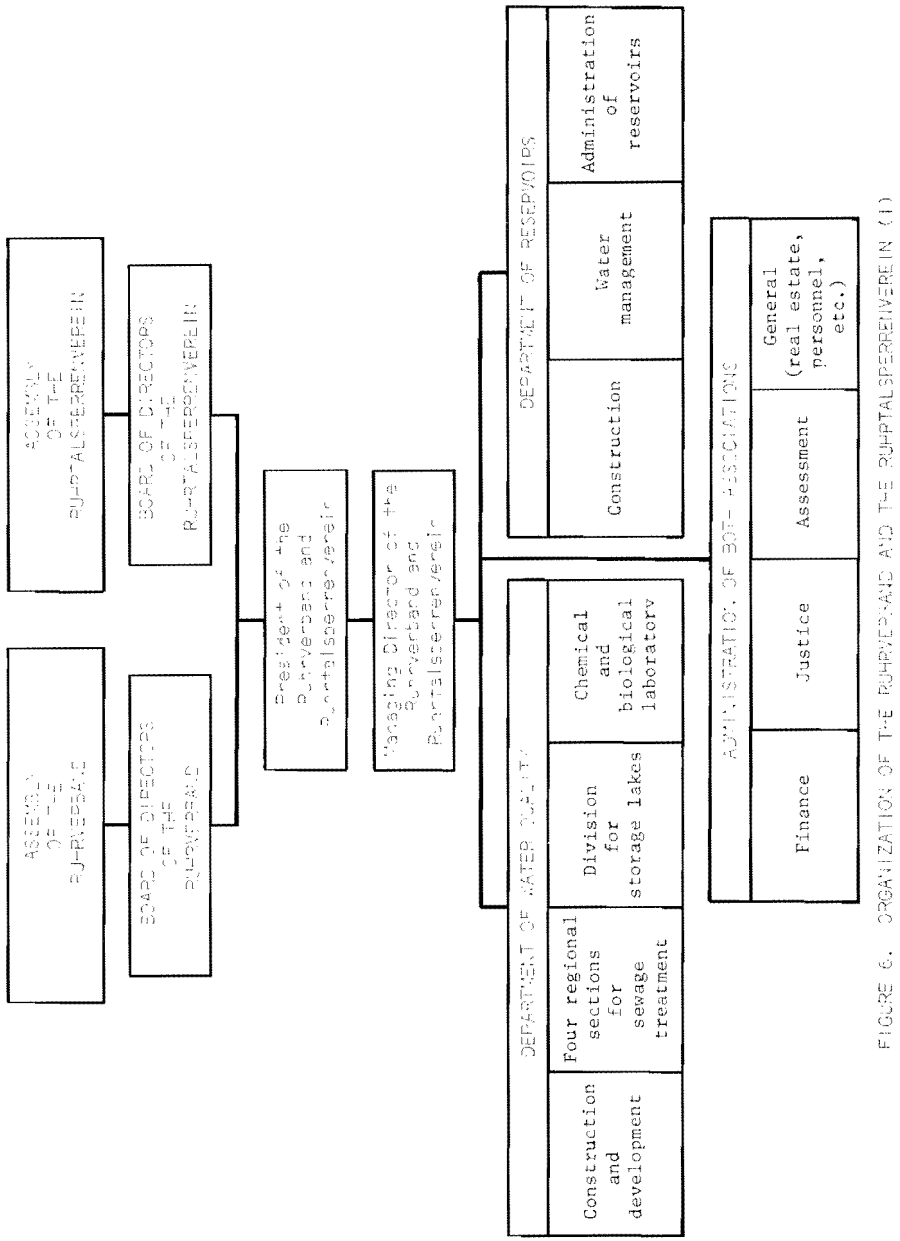


FIGURE 6. ORGANIZATION OF THE RUHRVERBAND AND THE RUHRTALSPERRENVEREIN (1)

Construction funds are obtained from the capital market by the sale of bonds. A system of charges is, however, used to meet the annual expenses for interest, operation, maintenance and replacement. These charges are based upon the amount and quality of the effluent discharged. Members may appeal their charges to a commission established by the Ruhrverband or finally to the courts. The Minister of Food, Agriculture and Forests of North Rhine-Westphalia has general supervisory powers aimed at ensuring that the charges follow the form prescribed by the enabling legislation establishing the association. The approved charges are public obligations enforceable by law as taxes. Relationships have, however, been such as to require very little enforcement. As Kneese and Bower state (1, p. 262), "this favorable experience, plus the public character of the obligations, has given the Genossenschaften such a strong credit rating that there is an international market for their bonds."

The River Authorities of England and Wales

The detailed study and analysis of water management arrangements in England and Wales by Craine (20) is the main source of information in this section. Kneese and Bower (1) have also discussed and analyzed the approach used in these countries.

The existing institutional arrangements operating in England and Wales stem from the Water Resources Act of 1963 (74). Craine (20, p. 23) presumes that the act applies only to England and Wales as there are "the only hydrologically related political units of Great Britain." Scotland, he points out, is separated from England by the Cheviot Hills and is virtually self-contained with respect to fresh water resources.

The Water Resources Act of 1963 is the culmination of twenty years of efforts aimed at achieving greater governmental involvement in water supply and better coordination of water supply considerations with the earlier established river development responsibilities of government (20). Craine (20, p. 29) further states that:

> The 1963 Act establishes a highly decentralized policy and administrative system for comprehensive water management, one with explicitly prescribed procedural linkages to central government, through which it is expected that national and interregional interests will be expressed and broad policy supervision be exercised ...

The administrative system is comprised of three major agencies of the central government and twenty-nine local River Authorities encompassing all England and Wales as shown in Figure 7. The central government expresses its responsibility to promote the conservation and proper use of water resources and the provision of adequate water supplies through the Ministries of Housing and Local Government, and Agriculture, Fisheries and Food. The third central government agency is the Water Resources Board, placed administratively within the Ministry of Housing and Local Government and given wide ranging responsibilities for policy, planning, and coordination of local water management schemes with national and interregional needs.

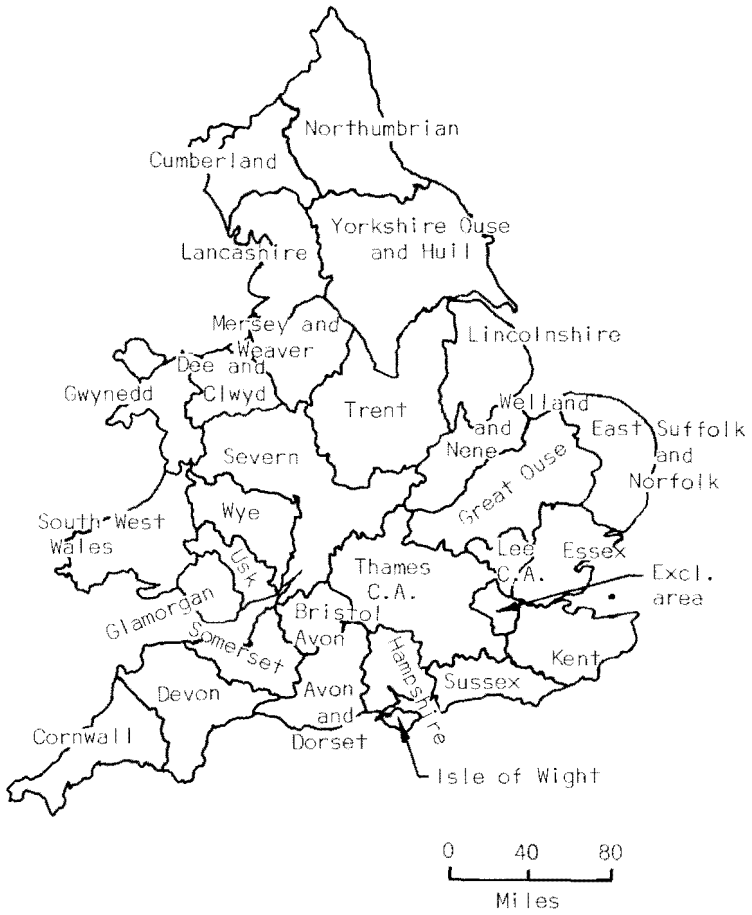


FIGURE 7. AREAS OF RIVER AUTHORITIES IN ENGLAND AND WALES (20)

Cabinet Ministries. Each of the cabinet ministries have both specific and general responsibilities regarding water resources.

The Minister of Housing and Local Government's specific responsibilities concern municipal water supply and sewage disposal. In this respect his major powers relate to (a) the rationalization and operation of water supply services provided by both private and local government agencies, and (b) the provision of sewage disposal facilities by local authorities. The four major areas of supervisory control exercised by this ministry include the determination of "minimum acceptable flows," the licensing of abstractions, the approval of charging schemes, and the granting of consents for effluent discharges. This ministry, apart from its water related powers, exercises a wide range of supervisory authorities over local government operations including those of financing and planning.

The Ministry of Agriculture, Fisheries and Food exercises general and specific control over the drainage, flood control and fisheries activities of River Authorities. In particular, it recommends grants-in-aid for drainage and flood protection projects and provides policy guidance on the administration of fishing regulations and fishery improvements.

The two ministries share the general supervision of the River Authorities with particular reference to their establishment, membership, and general operating policies. They hear and arbitrate appeals against the actions of River Authorities, and can exercise either special or general default powers over these actions. In particular, the Ministers can transfer functions not being executed by a River Authority to a Minister, the Water Resources Board or an adjoining River Authority.

In fact, states Craine (20) the Ministerial powers are quite limited. The Ministers have little authority to initiate action except by their default powers.

The Water Resources Board. Craine (20, p. 84) describes the Water Resources Board as providing "for the first time a central focus for the national concern about water resources and their effective development and management."

The Water Resources Act of 1963 stipulates that the Board shall be comprised of not more than eight members appointed by the Minister of Housing and Local Government. The Minister also appoints a chairman and deputy chairman from among the members. The only explicit qualification required of the members is that at least one of them have "special knowledge or experience of matters relating to the conservation and use of water resources in Wales" (74, p. 14). Craine (20, p. 86), however, states that the Board has actually been chosen to represent the "whole scope of water affairs."

The powers and functions of the Board are described as falling into two categories: (a) formulating and expressing a national perspective concerning water resources, and (b) providing central leadership to River Authorities in performing their "new functions" relating to water

conservation in the context of ensuring adequacy of water for withdrawal uses (20).

With respect to providing a national perspective, the Board is authorized to collect, collate, and publish relevant water resources data including prospective needs; advise the Cabinet Ministers with respect to their joint and separate responsibilities; recommend action for securing proper conservation, development, and use of water resources; and undertake or sponsor research and submit reports as required by the Board or requested by a Minister.

In providing leadership to the River Authorities, the Board may advise on their water conservation responsibilities, reviewing and recommending revisions of their actions; encourage and assist in the preparation and finally approve plans for water transfers; review progress and recommend action with respect to pollution abatement; and advise the Ministers of Authorities in default of their responsibilities, and the assumption of those responsibilities should Authorities fail to comply with Ministerial orders.

The Board has assumed a positive leadership role to River Authorities with respect to policy and procedural guides. During its first year of operation, it developed six comprehensive memoranda, clarifying, interpreting and suggesting procedures for implementing the new statutory provisions (20).

Craine (20) also attested to the Board's urgency in assembling a professionally competent staff with which to execute its functions. He anticipated that the Board, though sharing policy and leadership roles with the Ministries, might quite quickly become the central water management agency.

River Authorities. The membership of River Authorities is generally limited by law to between twenty-one and thirty-one but may be greater under special circumstances. Of this membership, local governments in the area of jurisdiction of each Authority are required to appoint a bare majority. These appointees may or may not be members of the constituent councils of these local governments. The remaining members of the River Authorities are appointed by the two Cabinet Ministers earlier mentioned on the basis of their qualifications (experience of demonstrated capacity in or special knowledge) in drainage and flood control, fisheries, agriculture, public water supply, and industry. Craine (20, p. 84) has described the River Authority as "the instrument for creating a partnership between local governments and the national government in designated water regions." Note that contrary to general American practice, the regions are stipulated in the enabling legislation subject to revision by the Ministers who are also empowered to appoint the dates of establishment of Authorities. American practice generally leaves the establishment of watershed and other similar districts and regional commissions to follow the petitions of local governments. As a result many years elapse with only a few of the intended organizations established, thus defeating the purposes of the legislation.

River Authorities are required by the Water Resources Act of 1963 (74, p. 4) to take such action as may be necessary, expedient or as directed

> ... for the purpose of conserving, redistributing or otherwise augmenting water resources in their area, of securing the proper use of water resources in their area, or of transferring any such resources to the area of another river authority.

These Authorities are in most cases the initiators of water management actions with a wide latitude in decision making. The following are the authorized functions of each River Authority (20, pp. 82-84):

1. Provide for systematic collection of hydrologic data and of water use information.
2. Conduct water resource surveys, including analysis of supply and demand relationships, and development of proposals for actions.
3. Determine a "minimum acceptable flow" (or level) at critical points in the water systems of their areas to serve as a standard to guide decisions regarding water management.
4. Administer pollution control legislation, including particularly the issuance of "consents" to discharge waste water into the natural water bodies.
5. License withdrawals from ground and surface water resources.
6. Maintain surveillance of fishing conditions and issue fishing licenses.
7. Plan, construct, and operate water developments for the purpose of land drainage, flood control, fisheries improvements, water conservation for domestic, industrial and agricultural purposes, and, in some instances, for navigation and harbour improvements.
8. Co-ordinate non-Authority water development projects to better achieve their contribution to an integrated scheme of water management.
9. Secure funds to finance water resources developments and to cover costs of their operations and administrative needs of the River Authority itself.

The Water Resources Act of 1963 has provided for a highly decentralized system of water management of which the River Authorities are the key. It is within these Authorities that the basic conflicts associated with water management decisions are faced (20).

Financing. Three main sources of financing are available to River Authorities (20): (a) precepts or assessments levied against other legally recognized local authorities and special districts for a variety of purposes, (b) water user charges on licensed withdrawals, and (c) grants from the central government. The general relationship among these revenue sources are depicted in Figure 8.

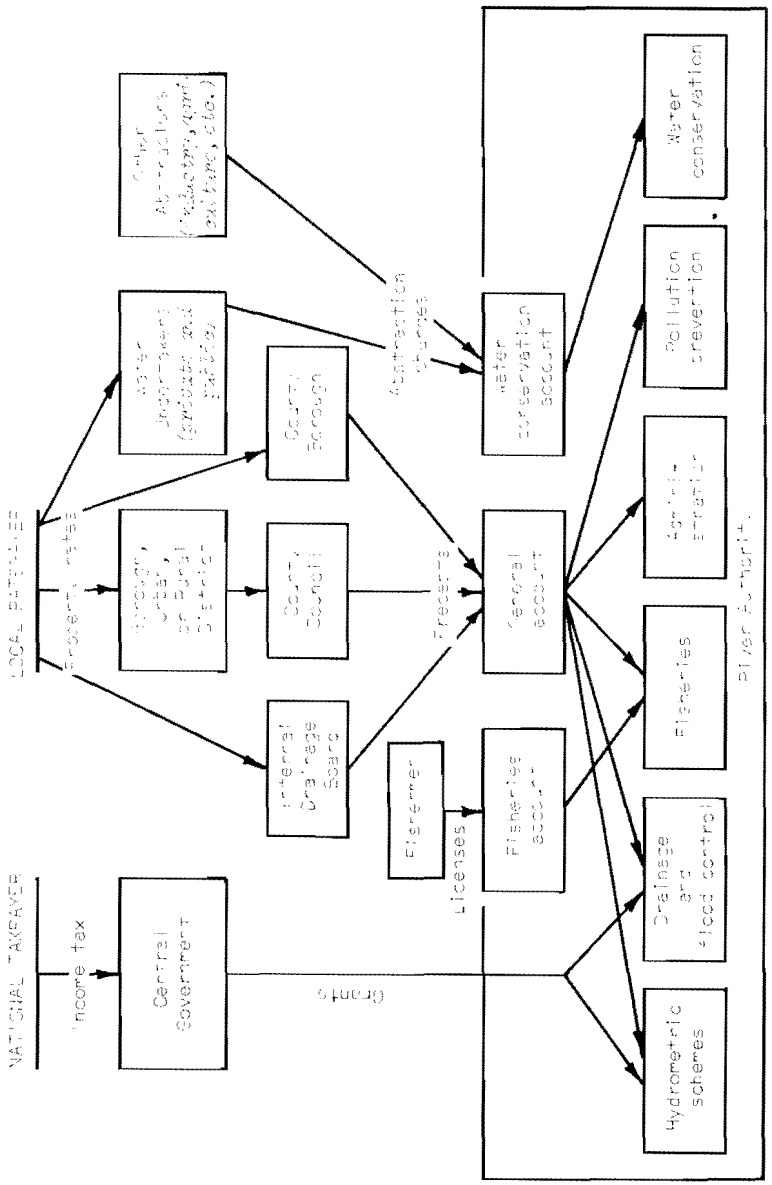


FIGURE 8. NET-FLOWS OF FINANCING BY RIVER AUTHORITIES IN ENGLAND AND WALES (20)

The French Basin Agencies

This section is the description of Kneese and Bower (1).

The French Basin Agencies were created by national law in December, 1964, following the report of a Commission on Water established in 1959 as a result of general discontent with the record of pollution control and the fragmentation of responsibility.

Despite France's lesser experience with regional water management agencies than both West Germany and England, the law establishing the French Basin Agencies was aimed at surpassing many features in these countries particularly in the use of economic incentives for water quality management (1). Three important features of the French law are: (a) the establishment of Agencies in each of the six river basins of France shown in Figure 9; (b) the authorization of these Agencies to implement regional programs of water quality management; and (c) the placing of primary emphasis on charges, particularly effluent charges, for financing the program and coordinating private and local government waste discharge decisions with the regional Agencies' objectives.

Unlike the British Water Resources Law of 1963, this Act is extremely general and termed a skeleton enactment by the French. It leaves to the administration the translation of provisions in the Act to rules. The Basin Agencies are given general water resources management powers in recognition of the water quality problems as an integral part of water resources management. The Agencies are, however, not specifically authorized to construct and operate collective facilities though it is foreseen that grants, loans and contracts with private and public bodies will be used to achieve the same results.

The River Basin Agencies will be supervised and coordinated by the central government as indicated in Figure 10. Management areas were mapped out by the Standing Interministerial Committee on development planning problems. The National Water Committee under the direct authority of the Premier advises on water resource problems of major importance or with interbasin effects. The water users, local communities, and the administration are to be equally represented on the River Basin Committees to be set up in each basin or group of basins where appropriate. These Committees will advise on the desirability of development works but approval of the central government is required before execution.

It is worth noting that the original plan to set up Agencies only in areas with particular problems was dropped in favor of establishing them throughout the country, each Agency encompassing a whole hydrologic area. The reason for so doing was the recognition of the interdependence among users throughout a river basin. In recognition of the possible need for geographical decentralization in large river basins, the question of the establishment of sub-basin agencies operating with considerable freedom under the general authority of a basin-wide agency was left open.

The Basin Agencies are authorized by law to levy charges on corporations and individuals "taking into account the extent to which they have made the provision of facilities useful or necessary or will benefit

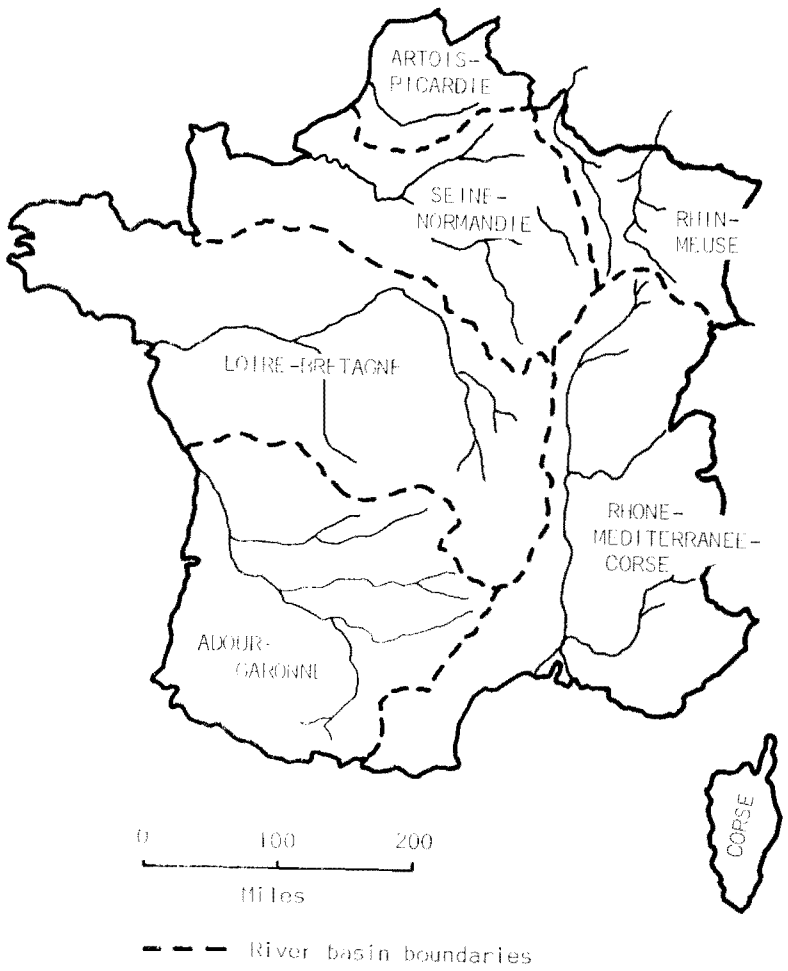


FIGURE 9. RIVER BASINS OF FRANCE (1)

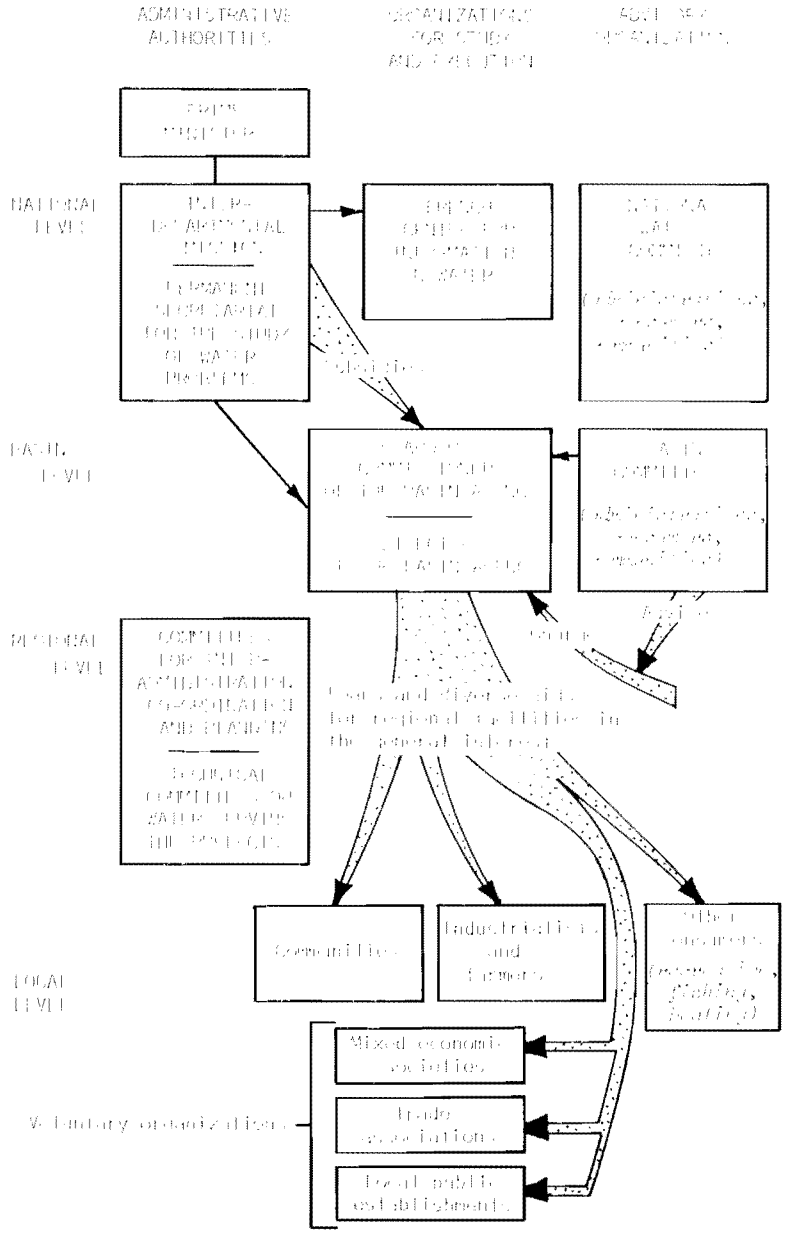


FIGURE 10. THE FRENCH ORGANIZATION FOR WATER RESOURCES MANAGEMENT (1)

therefrom." These charges while viewed as a means of financing large scale facilities are also intended to compensate for the external costs imposed on the general economy.

The Ontario Water Resources Commission

Ontario, Canada's central Province, is also its second largest with an area of 412,562 square miles, nearly five times the size of Minnesota. Its inhabitants number seven million, about one-third of Canada's population. Nearly 90 percent of its population lives in the highly industrialized southern region contained between Lakes Huron, Erie and Ontario south of Georgian Bay (Figure 11). Pleva (75) describes southern Ontario as that part of Canada, more than any other, that resembles the major northern and midwestern areas of the United States. It is with the Province of Ontario that Minnesota shares its northern border.

The similarity between parts of Ontario and the northern and midwestern United States may be extended to their water resources management problems of recent years. Indeed they share the common problems of the vast Great Lakes of North America. It was also the all too familiar problems of threatening water shortages, inadequate water pollution control systems and water management administrative framework characterized by a multiplicity of agencies that led to the creation of the Ontario Water Resources Commission by an Act of the Ontario Legislature in 1956.

The Ontario Water Resources Commission Act of 1956, since revised and amended many times (76), authorizes the Commission to be comprised of three to seven persons appointed by the Lieutenant Governor in Council of the Province. The Lieutenant Governor in Council must appoint a Chairman and may also designate a Vice-chairman from among the members. All Commission members hold their offices at the pleasure of the Lieutenant Governor in Council. The Commission is presently composed of five members including a Chairman and Vice-chairman. It employs a General Manager to administer its programs and a staff of about 1000 (77).

The Commission exercises autonomy in the execution of its programs but must report to the Legislature through a Minister designated by the Lieutenant Governor in Council. The currently designated Minister is the Minister of the Department of Energy and Resources Management. The Commission is the principal agency responsible for water management in the Province of Ontario. Its relationships with other agencies exercising water management responsibilities are described later. The Commission exercises a wide range of responsibilities that fall into two broad categories: (a) supervision of the water resources of the Province including distribution and quality control, and (b) financing, construction, and operation of water supply and water pollution control porjects. Its specific functions as authorized by law are (76, p. 7):

> 1. to control and regulate the collection, production, treatment, storage, transmission, distribution and use of water for public purposes and to make orders with respect thereto;
> 2. to construct, acquire, provide, operate and maintain water works and to develop and make available supplies of water to municipalities and persons;

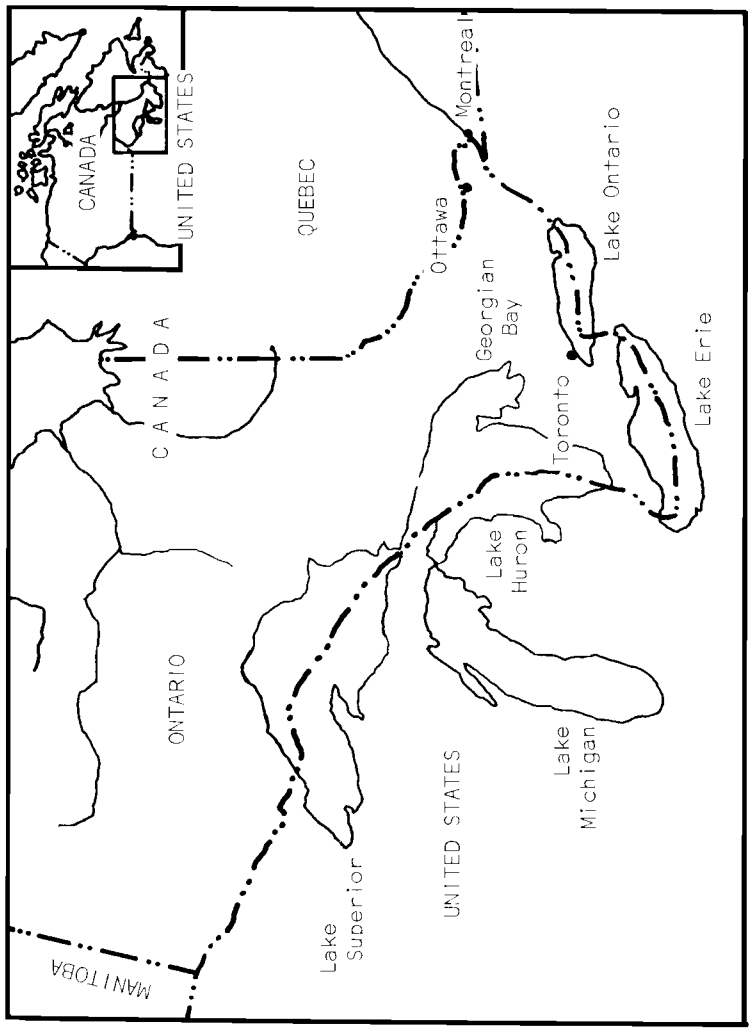


FIGURE 11. THE PROVINCE OF ONTARIO, CANADA
Adapted from (75)

3. to construct, acquire, provide, operate and maintain sewage works and to receive, treat and dispose of sewage delivered by municipalities and persons;

4. to make agreements with any one or more municipalities or persons with respect to a supply of water or the reception, treatment and disposal of sewage;

5. to conduct research programmes and to prepare statistics for its purposes;

6. to disseminate information and advice with respect to the collection, production, transmission, treatment, storage, supply and distribution of water or sewage, and to charge fees in respect thereof; and

7. to perform such functions or discharge such duties as may be assigned to it from time to time by the Lieutenant Governor in Council ...

The Commission exercises its regulatory functions by systems of permits, licenses, plan review, and approval. Permits are required for water withdrawals for all purposes in quantities exceeding 10,000 gallons per day and, in some special cases, for lesser quantities. The addition of substances to water courses (including groundwater ones) for the purpose of destroying or otherwise controlling plants, fish, insects and other living matter is also regulated by permits. Licenses are used to regulate well drillers. Plan reviews and approval by the Commission are required before the construction, extension, or alteration of all water works and sewage (inclusive of all wastes) works by municipalities, industrial firms and individuals. Owners of water and sewage works must also submit returns on matters pertaining to these works as required by the Commission. The Commission is authorized to order the execution of water and sewage works by municipalities, industries and private concerns as it sees desirable. Upon failure to implement such orders, the Commission may undertake the works and operate them at the expense of the defaulter. The Act specifies penalties for failure to comply with all of the above measures.

The Act authorizes the Commission to enter into agreements with municipalities to build and operate water supply and sewage disposal projects on their behalf. For this, municipalities must repay the full capital costs and interest, operation, maintenance, administration, and insurance costs, and make a contribution to the Commission's reserve accounts used to cover renewals, replacements, project improvements, and contingencies. Disputes between the Commission and municipalities over the latter's payments must be referred to a sole arbitrator appointed by the Lieutenant Governor in Council for settlement. The award is final and binding.

The Commission is also authorized to make regulations, subject to the Lieutenant Governor in Council's approval, covering a wide variety of matters including water quality standards for potable and other water supplies, sewage and industrial waste effluents, receiving streams, and water courses.

During a personal interview in August, 1969, M. H. Cathcart, Assistant to the General Manager, indicated that planning activities are undertaken by the Commission in close cooperation with municipalities. W. A.

Steggles, Supervisor of the Commission's Water Quality Surveys Branch also indicated by letter dated July 24, 1969, that the Commission holds public hearings to permit community participation in the development of water supply and pollution control plans. The Commission's 1967 Annual Report (77) indicated that emphasis is being placed upon long range planning and regional studies. Steggles also stated that the Commission has been cooperating with, and advising the International Joint Commission in its investigations in the Great Lakes from which it is hoped that a basis for a comprehensive water resources management plan for the Great Lakes Basin will develop. The Commission (78) referred to its cooperation with the Canadian federal authorities in an inventory of the water resources of northern Ontario.

The Commission is essentially a self-sufficient, non-profit making agency with most of its capital coming from advances by the provincial government that are repaid with funds collected from municipalities. Working capital is also obtained by means of loans and overdrafts on banks subject to the approval of the Lieutenant Governor in Council. Though the Commission is authorized by law to issue and sell debentures guaranteed by the Province of Ontario, Cathcart, the Assistant to the General Manager, indicated that this method of raising capital had not been used.

Two other agencies with important water management roles are the *Conservation Authorities Branch* of the *Department of Energy and Resources Management* and the *Hydro-Electric Power Commission of Ontario* (79). The latter, a corporate self-sustaining entity with broad powers concerning electricity supply, also reports to the Legislature through the Minister of Energy and Resources Management. This permits the coordination of its activities with those of the Ontario Water Resources Commission (OWRC) and the Conservation Authorities Branch of the Department of Energy and Resources Management.

The main function of the Conservation Authorities Branch is the administration of 36 local Conservation Authorities in the province (79, p. 7). These Conservation Authorities are independent corporate bodies each with jurisdiction over an entire watershed and established following the petition of two or more municipalities in a watershed (75). They are administered by officials appointed by the municipalities on a population basis. Their main function is the construction of water conservation and flood control projects including dams, reservoirs, and channel improvements (79).

Other provincial agencies with water management related responsibilities include (79):

Department of Agriculture -- administration of farm water supply programs and the Federal-Provincial assistance program for rural water supply; acquisition of natural water storage areas; and drainage outlet improvements.

Department of Lands and Forests -- administration of the Lakes and Rivers Improvement Act related to the construction of dams on public and privately owned lakes and rivers; management of Crown Lands; and provision of water storage for fish and the protection of wild life from

forest fires.

Department of Public Works -- construction and maintenance of dams, locks, and navigable channels at the request of other government departments.

Department of Municipal Affairs -- administration of grants for the construction of drainage works under the Drainage Act; and urban land management as indicated by Steggles, Supervisor, Water Quality Surveys Branch, Ontario Water Resources Commission in a letter dated July 24, 1969.

Department of Health -- public health considerations of drinking and bathing water quality.

Department of Economics and Development -- economic aspects of water resources policies and their effects upon economic development.

Department of Tourism and Information -- concern with water supply and pollution problems as they affect tourism.

Patterson (80) has discussed the role of the *Canadian Federal Government* in water resources management. This role is considerably influenced by the British North American Act of 1867 which made the administration of water resources within provincial boundaries the responsibility of provincial authorities but endowed the Federal Parliament with jurisdiction over navigation, fisheries, water in national parks and Indian reserves, along or crossing the international boundary and, in some circumstances, over interprovincial waters. Many federal agencies execute these responsibilities, most of them being data collecting or regulatory agencies. A new Act is now under consideration by the Federal Government aimed at initiating a joint Federal-Provincial approach to Canada's water conservation problems, particularly water pollution (81).

The Delaware River Basin Commission

The Delaware River Basin Commission (DRBC) was created in 1961, some forty years after the idea of setting up an interstate compact for the comprehensive development of the basin's water resources was first suggested (1). The Interstate Commission on the Delaware River Basin (INCODEL), established in 1936 by parallel legislation by the States of Delaware, New Jersey, New York and the Commonwealth of Philadelphia has been described as an agency that operated on the principle of voluntary cooperation and, therefore, not an interstate compact agency. INCODEL did little in the way of multipurpose planning and showed a preference for parallel State legislation (1).

The excessive damage done to lives and property in the basin by two severe hurricanes in 1955 led to the undertaking of a planning study by the U. S. Army Corps of Engineers and the setting up of the Delaware River Basin Advisory Committee by the four basin States to assess the water problems in the basin. This Advisory Committee drafted a compact for the establishment of a regional water management agency. Prompt

action by the States and Federal agencies led to the approval by Congress in 1961 of the Delaware River Basin Compact, Public Law 87-328, establishing the Delaware River Basin Commission.

The Delaware River Basin Commission has been described as "the only interstate-federal compact agency in the United States and the only regional agency to be given such comprehensive powers" (1, p. 279). The compact establishing the Commission has as a central objective the creation of an agency that would develop and administer a comprehensive multipurpose water resources plan aimed at achieving the greatest benefits and producing the most efficient service in the public welfare.

The Commission is comprised of five members, the Governors from each of the four States originally involved in INCODEL (ex officio), and one, currently the Secretary of the Interior, to be appointed by the President of the United States. Each commissioner is authorized to appoint a voting alternate who can attend all meetings of the Commission. No qualifications are specified for these alternates, but they have generally been knowledgeable men in the field of water management (1).

The Commission is charged with the development of a comprehensive plan for the immediate and long-range development and use of the basin's water resources (see Figure 12) and, based on that plan, a shorter-range water resources program. The Commission's powers for planning and implementing water resources development include the acquiring or building, operating, and maintaining of water supply facilities; flow regulation for water quality control; pollution abatement and control; flood protection; watershed management including the prevention of soil erosion, and the promotion of land reclamations, sound forestry practices and fishing and wild life conservation measures; development and operation of hydroelectric power facilities (except direct power distribution to consumers); and regulation and control of water withdrawals and diversions from the basin.

The Commission can delegate certain of its powers to instrumentalities of signatory governments and can establish cost-sharing standards and formulas for the apportionment of costs of multipurpose programs among purposes and also among the signatory parties, public and private concerns.

The Commission has the power of eminent domain with all signatories (State and Federal Governments) bound to the undertaking of no development projects in the basin without the approval of the Commission and in accordance with its comprehensive plan. This is not to be interpreted to mean, however, that the Federal Government has relinquished its responsibilities with respect to the control of navigable waters and the regulation of commerce among States and with foreign nations. Further, it is intended that the Commission shall exercise its broad powers for the *direct* implementation of various water management measures only in the absence of adequate implementation by another Federal or State agency.

Specifically, with respect to water quality management, the Commission can invoke the powers and jurisdiction of States and Federal water quality control agencies as a complainant against waste dischargers.

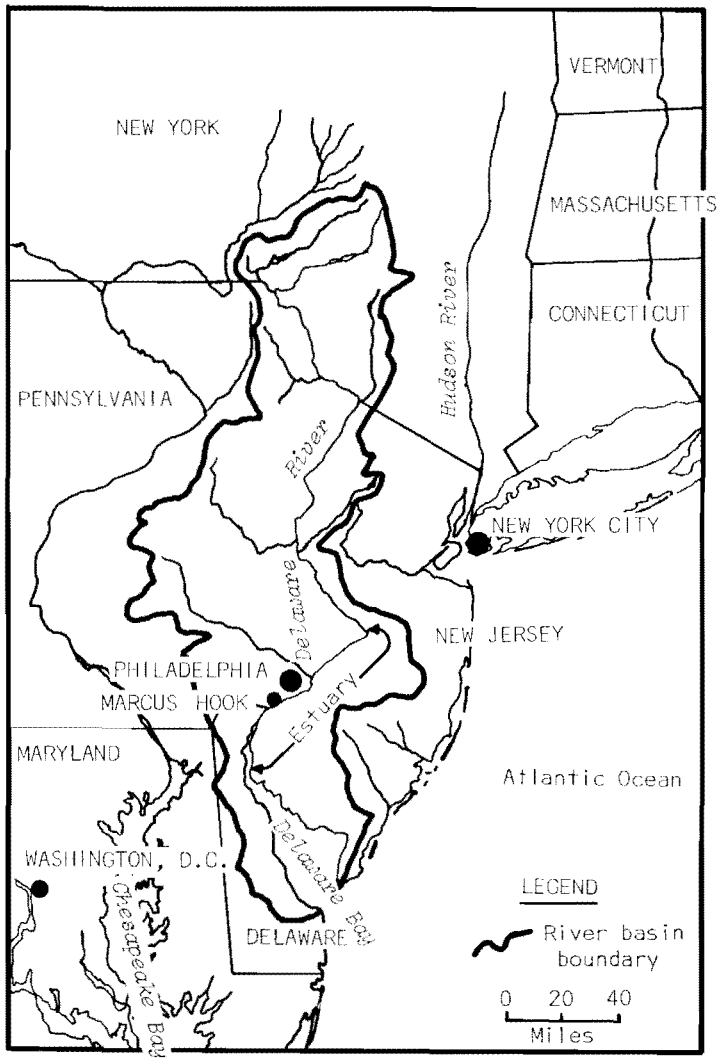


FIGURE 12. THE DELAWARE RIVER BASIN (1)

Subject to investigation and public hearings, the Commission may assume jurisdiction over planned waste discharges if the comprehensive plan requires it. The DRBC can classify and set quality standards for the waters of the basin after the holding of public hearings. The signatory parties are required to pass legislation for the control of waste discharges in accordance with the comprehensive plan. The Commission, however, has direct enforcement powers in this area that it can use after investigations and hearings and subject to appeals in competent courts of jurisdiction.

The compact requires the provision of capital for project execution by the signatories in accordance with the cost-sharing provisions established by the Commission. It also gives the Commission power to raise loans and issue bonds. The annual expense budget of the Commission is shared among the signatories in their respective budgets subject to the approval procedures of their respective budgetary processes.

The Commission in the spring of 1969 was organized in two divisions, administrative and planning, under an Executive Director. The Planning Division included Water Quality, Program Planning, Project Review, and Operations branches. A visit with officials of the Commission indicated that it was not yet directly involved in construction activities but was moving cautiously to design, construct, and operate regional water quality control systems, two of which, the "Deepwater" and "Marcus Hook" were in the planning stages. The Operations Branch was then quite new and without a substantial program. The Program Planning Branch was functioning in most areas except power and flood control while administering the comprehensive plan originally drawn up by the Corps of Engineers, updating it periodically as required, and assuring compliance with it by all water users and developers. The effluent charges proposal for the control of waste discharges, referred to earlier, had not been implemented. Inadequate staffing and some skepticism of the practicality of implementing the proposal were the reasons given for failure to do so. Instead, a waste allocation system based on uniform secondary treatment was in use. It was indicated, however, that effluent charges were proposed for use in controlling waste discharges to the regional waste treatment plants then being planned.

The Wisconsin Department of Natural Resources

The Wisconsin Department of Natural Resources was created in answer to a "clear need for improvement in the way we plan, use, manage and protect" the State's water resources (82, p. 2). The Department of Resources Development created by the Water Resources Act, Chapter 614 of the Wisconsin Laws of 1965, preceded it. By this Act, the water regulatory responsibilities of the Board of Health, the Committee on Pollution and the Public Service Commission were transferred to the new Department of Resource Development. This department was subsequently combined with the Department of Conservation and the State Lands Department by the Reorganization Act, Chapter 75 of the Wisconsin Laws of 1967, to form the Department of Natural Resources. There are seven other State agencies that share in planning for water resources management in Wisconsin. Their areas of concern will be discussed later. Primary responsibility for

water resources management in the State is, however, assigned by law to the Department of Natural Resources (82).

The goals of the Department of Natural Resources have been listed as (82, p. 3):

> 1. To provide the legislature and the general public with factual information about Wisconsin water resources and their management;
> 2. To coordinate water resources management decision-making processes within the framework of existing legislation and policy; and
> 3. To suggest and conduct analyses of proposed changes in major policies to create procedures for more rational planning for use of our water resources.

The development and periodic updating of a comprehensive water resources plan is seen by the Department as an important tool in attaining those goals.

The Department of Natural Resources inherited the activities of the former Department of Conservation concerned mainly with the establishment of policies governing the management of watersheds, small woodlands, wetlands, water uses and springs; the construction of dams and the impoundment of water; land control acquisition, long-range recreation planning; public access to lakes and streams; and public rights to navigable waters. Also associated with these were research and the dissemination of information on the State's water resources conservation problems. The conservation oriented activities of the Department of Natural Resources were also broadened to include the setting of recreational seasons (hunting, etc.) and advertising of recreational resources; the establishment and implementation of long-range conservation plans and projects; the taking of conservation easements; the conducting of State-aid programs with towns and counties promoting public access to navigable waters; and a similar program for counties developing outdoor recreational facilities on Forest Crop Lands.

The general objectives of the water related responsibilities of the Department, executed by its *Division of Environmental Protection*, are (82): (a) to develop and implement water quality regulatory measures; (b) to efficiently and effectively administer State and Federal funds for water resources development; (c) to provide leadership in planning the management and use of the State's water resources; and (d) to review and coordinate the activities of agencies involved with water resoruces.

The Division influences water resources planning in three ways: (a) establishing and enforcing water quality standards; (b) regulating uses of water and related land resources; and (c) developing comprehensive water management and development plans.

In recognition of the interrelationship between air pollution, solid waste disposal, and water pollution the State has placed its responsibility in all three areas in the Division of Environmental Protection.

This Division concentrates the major share of its activity in developing guide-lines, reinforced by financial incentives and legal action, for local and private action (82). By June 1969, the Department had not executed its authority to construct pollution abatement facilities for communities financially unable to do so, according to the Department's Assistant Secretary. This official, however, pointed out that the authority may soon be exercised if funded by the Legislature.

Governor Knowles, in a speech on September 28, 1966 to the American Water Works Association, Wisconsin Section, stressed the Department's authority to construct pollution control facilities at the expense of those who have failed to comply with orders to build such facilities. It seems therefore, that it is intended to use its authority to construct works. However, it does appear that the Wisconsin Constitution has been interpreted as prohibiting the State "from contributing to or engaging in certain works of internal improvement" (83, p. 49).

In the area of land-use management, the Division of Resource Development has very strong flood plain and shoreland protection programs requiring local governments to enact ordinances meeting the Division's minimum requirements. Subject to the holding of public hearings, the Division can enforce its own ordinances in the jurisdictions of defaulting local governments.

Financing. The main source of financing of the Department of Natural Resources is that of State appropriations (83, pp. 57-58). Some funds are raised through special taxes, including a cigarette tax used for conservation activities. The State's bonding program also provides funds for subsidizing municipal sewage treatment facilities. The feasibility of a system of effluent charges for the control of waste discharges is currently under study (47). If implemented this may provide another source of funding for waste disposal facilities and possibly other water resources works.

Organizational arrangements. The Department of Natural Resources operates through five regions into which the State has been divided (Figure 16) in accordance with the Water Resources Act of 1965 (82). Regional Advisory Boards have been established in each region to advise on water problems and provide liaison with the public. Each consists of five Governor-appointed citizen members and single representatives from the Department of Health and Social Services and the Department of Natural Resources. These Boards must meet at least semi-annually or at the call of the Chairman or a majority of its members, under the chairmanship of the Regional Director of the Department of Natural Resources.

A seven-member Natural Resources Board formulates the policies of the Department for execution by a Director appointed by the Board. The Natural Resources Board includes one citizen member selected by each Regional Advisory Board. The Natural Resources Board is advised by a Technical Advisory Committee consisting of representatives of the Department of Health and Social Services, the Department of Natural Resources, the Soil Conservation Board, and the Geological and Natural History Survey.

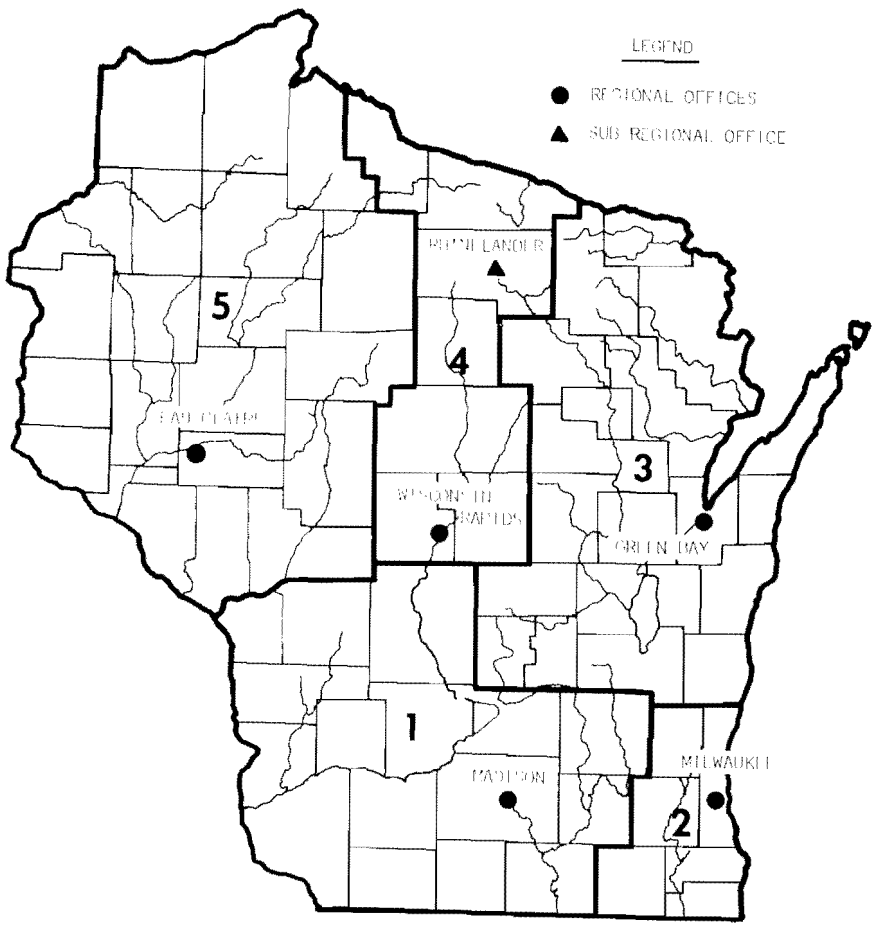


FIGURE 13. REGIONAL AREAS FOR WATER RESOURCES MANAGEMENT IN WISCONSIN (82)

Other State agencies and their water management related responsibilities are as follows (82):

Department of Administration -- with responsibility for comprehensive State planning, this department provides the framework for natural resources planning by the Department of Natural Resources.

Department of Local Affairs and Development -- established to assist local governments in carrying out their functions, it works with these governments in attracting industry, and developing comprehensive land use plans and recreational projects.

Department of Agriculture -- its regulation of the use of herbicides and pesticides is of interest to the Department of Natural Resources which also exercises some regulation because of the effects of the chemicals on fish and wildlife and their use in forestry and vegetation management.

Department of Higher Education -- this department includes three agencies attached to the University of Wisconsin at Madison, each with a direct interest in water resources planning. These are:

1. The *Soil Conservation Board* which provides liaison between the local interests, State, and Federal Governments in the administration of the Federal small watershed program.

2. The *Wisconsin Geological and Natural History Survey* charged with responsibilities for investigating the State's geological resources, the surveying of water power sites, surface water, stream flow, and other related investigations.

3. The *Water Resources Center* with primary function to provide an interdisciplinary approach to water resources study and research. It is a clearing house for the administration of Federal, State, and other research funds.

Public Service Commission -- regulates municipal water and sewer rates and authorizes the construction of sewer and water plants by municipalities.

The Natural Resources Council of State Agencies -- on which is represented all State agencies concerned with water resources, provides formalized coordination of these agencies and serves in an advisory capacity to the Natural Resources Board of the Department of Natural Resources.

Summary

The institutional and organizational arrangements for six approaches to water resources management have been briefly described. Common to all of these approaches is the recognition that water quality management must be an integral part of water resources management; that some form of centralized control is necessary; that the approach must be a regional one involving river basins and hydrologic systems; that management agencies must in addition to their intelligence, planning, and regulatory respon-

sibilities be empowered to construct and operate facilities; and that ways must be found for getting meaningful local participation in decision-making. A variety of methods have been used in the various approaches to achieve these ends.

CHAPTER 4

WATER RESOURCES MANAGEMENT IN MINNESOTA

Minnesotans often refer to their beautiful State as the "Land of Sky Blue Waters", or the "Land of 10,000 Lakes" as appears on motor vehicle license plates. The allusion in these descriptions to the vastness of the State's water resources is indeed justified. Minnesota's water surface area of just over 4,000 square miles accounts for 0.1 percent of the nation's water area and is exceeded only in Alaska, Texas, and Florida, only barely so in the last two. The State's lakes, now officially listed as 15,291 with areas larger than ten acres, include five of the sixteen largest inland fresh water lakes in the United States (23). In addition, there are 25,000 miles of streams in the State including the headwaters of the Mississippi River.

It seems, however, that contrary to the "Sky Blue Waters" claim, Minnesota is the word used by the Dakota Indians to mean "tinted or turbid water" and is the name given by them to the largest river lying wholly within the State (23). To the extent that some of the State's other rivers and lakes may now be termed "tinted" the Dakota Indians may be considered as seers.

The State of Minnesota provides a very good example of the effects of what was described in Chapter 1 as a "burgeoning urban - industrial - agricultural economy" upon a region's water resources. The interplay of population growth and concentration, competing water uses, and the conflicts stemming from these uses - described in Chapter 1 - is clearly seen to result in water quality deterioriation, apparent impending water shortages, and other effects pointing to the need for integrated water quality and water resources management.

This chapter briefly outlines the State's water resources and examines the current arrangements for managing those resources. It shows that what in effect exists is merely a limited form of regulatory control of the development and use of the resources and by no means management of the type discussed in previous chapters. Legal, institutional, and administrative arrangements as well as specific management problems are examined. Comparisons are made with the institutional criteria developed in Chapter 3 in order to establish current weaknesses and deficiencies and to set the stage for the proposals to be made in Chapter 5. Most of the basic information used in this chapter comes from the State Planning Agency's bulletin on "Background Information for Framework Statewide Water and Related Land Resources Planning in Minnesota" (23), and the set of working papers on which this bulletin has been based. Visits to agencies concerned with water and land resources in the State together with some of their publications provide supplementary and detailed information. Use is also made of newspaper clippings and specific study reports.

I. BACKGROUND INFORMATION

Location

Minnesota, situated in the North Central United States (Figure 14) occupies a central position on the North American Continent. It shares its northern boundary with the Canadian Province of Ontario, its eastern with the State of Wisconsin, its southern with the State of Iowa, and its western with the States of North Dakota and South Dakota. The State's 84,068 square miles fall within the boundaries of four of the nation's major river basin regions (Figure 14) for which Federally coordinated comprehensive water resources planning is in progress. These are the Souris-Red-Rainy Region to the north, the Great Lakes Region to the northeast, the Upper Mississippi River Region to the south, and the Missouri River Region to the southwest.

Geographical and Political Sub-divisions

A commonly used set of eight geographical divisions of the State is shown in Figure 15.

The *Border Lakes Region* is a lake and forest region which was heavily logged during the State's early history. Now reforested, much of the area constitutes State and national forests of considerable scenic and recreational value.

The *Arrowhead Region*, containing the well-known "North Shore of Lake Superior", is also the site of many State forests and recreational attractions.

The *Iron Range Region* besides being a major source of the State's wealth is also of geologic and historic interest and considerable recreational value.

The *Northwestern Prairie Region*, drained by the Red River, is an agricultural region specializing in grain and potatoes with some dairying. The marshy wilderness of the Red Lakes is reportedly larger than the similar area of the Florida Everglades (23).

The *Central Lake Region*, drained by the Mississippi River, contains thousands of lakes with which are associated many scenic forests. Its recreational value has made Minnesota famous.

The *Sand Plain Region* is an agricultural area requiring careful intensive cultivation and favorable weather for crop production.

The *Minnesota Valley and Southwestern Agricultural Region*, situated on the northern fringe of the Corn Belt, is well suited to extensive agriculture and farms occupy nearly 85 percent of the land.

The *Southeastern Mississippi Valley Region*, originally hardwood forests, is now farmland with heavily wooded blufflands along the Mississippi River that constitute a valuable resource.

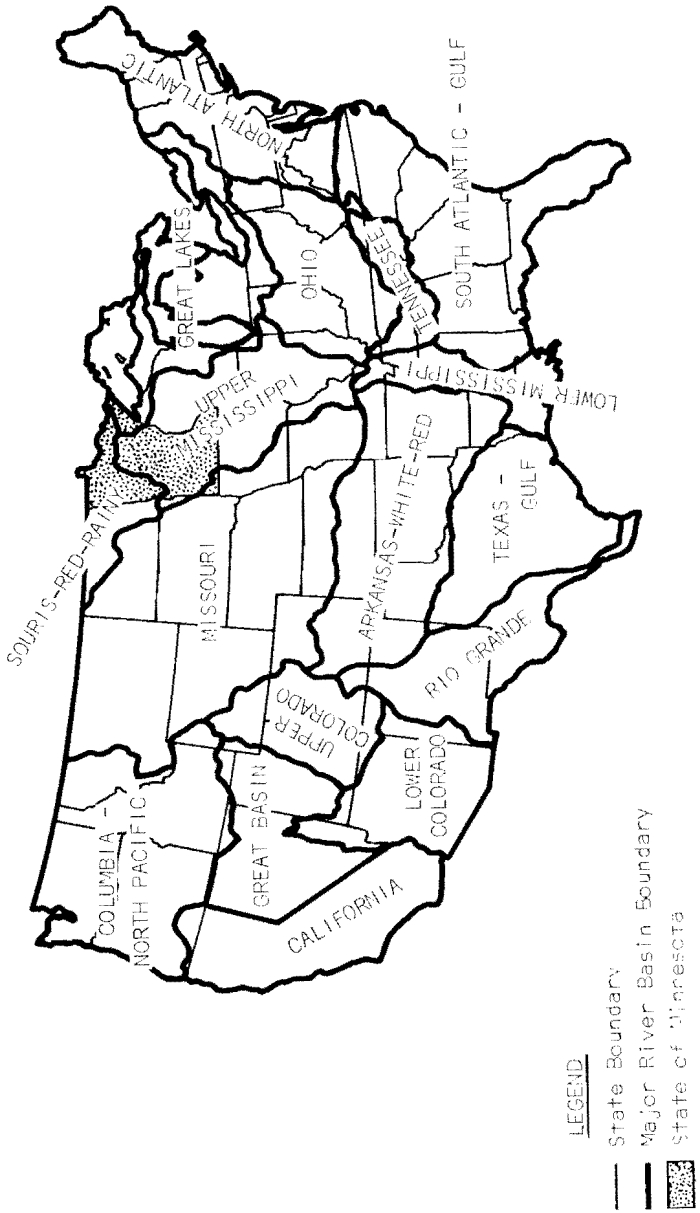


FIGURE 14. MAJOR RIVER BASINS FOR COMPREHENSIVE WATER RESOURCES PLANNING IN THE UNITED STATES
Adapted from (23)

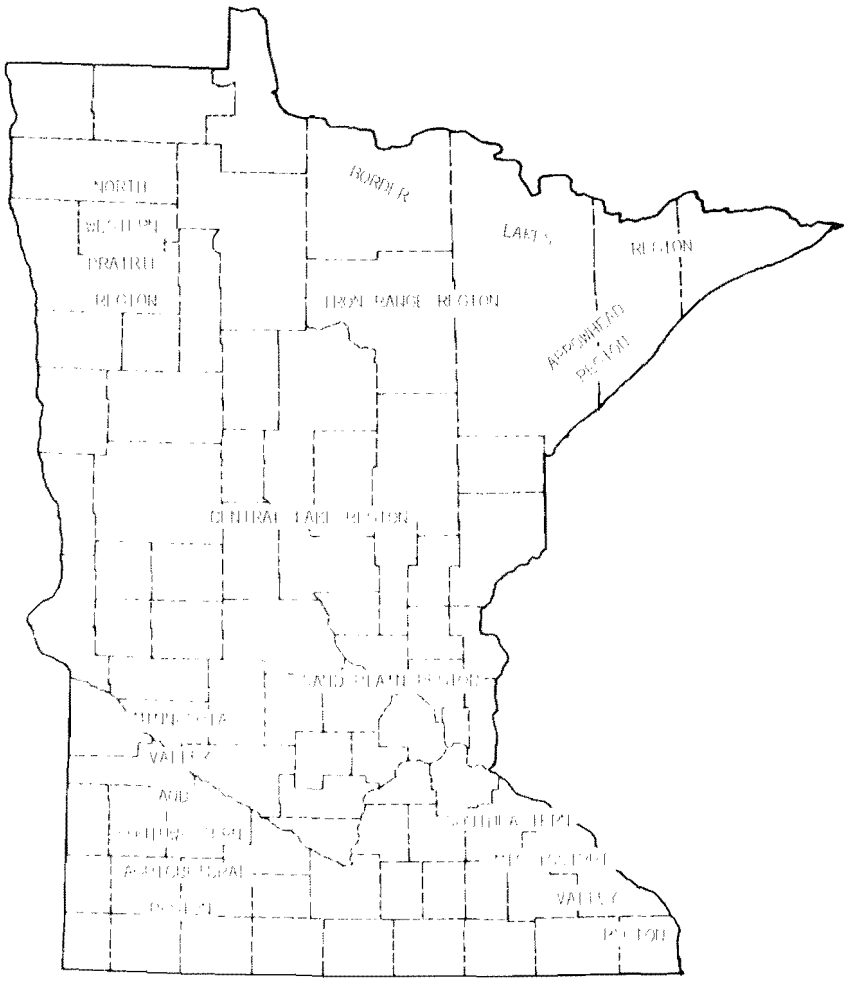


FIGURE 15. GEOGRAPHIC DIVISIONS OF MINNESOTA (23)

Politically the State is divided into 87 counties shown in Figure 16. The capitol city of St. Paul and its twin, Minneapolis, are included in what is known as the Metropolitan Area, comprised of the seven counties of Anoka, Hennepin, Ramsey, Washington, Carver, Scott, and Dakota.

Climate

Due to its mid-continent location, Minnesota's climate is a marked continental type characterized by rapid and wide temperature variations, scanty winter precipitation, and normally ample summer rainfall (84). The tendency to extremes in all climatic features is a little modified by Lake Superior and the large water areas within the State. The State lies in the paths of both the cold, dry arctic air masses sweeping southward from northwestern Canada, and the warm, moist tropical air masses moving north from the Gulf of Mexico (23).

Temperature. The average mean seasonal temperatures are 12.4°F in winter, 41.6°F in spring, 67.5°F in summer and 45°F in autumn (84). Maximum and minimum recorded temperatures are 114°F and -59°F, respectively, with the greatest recorded temperature range at a single site being 164°F at Ada (23). Except for the Iron Range Region and along the Canadian border where it is 90 to 100 days, the growing season ranges from 130 to 160 days which is ample for the production of the major crops (84).

Precipitation. The annual precipitation varies from about 19 inches in the northwest to 32 inches in the southeast with a State mean of about 25 inches. The State's high rank in agricultural production is influenced by the fact that a little more than one-half of the year's total precipitation normally falls in the four months of the growing season, May to August (84).

Most winter precipitation occurs as snow which annually averages 18 inches in the southwest to about 70 inches in the northeast. Eastern Cook County recorded the highest snowfall of 147.5 inches during the 1936-37 season (23). The water equivalent of new snow in the State varies from about 7 to 15 percent, i.e. each inch of new snow produces about 0.07 to 0.15 inches of water (23, p. 121). Snow conditions have been known to have considerable effects on runoff. While gradual melting results in much soil infiltration and low runoff, sudden thaws in the spring may cause rapid runoff of an entire winter's accumulation of snow (84).

Evapotranspiration. Evaporation and transpiration combined result in a loss to the atmosphere of 65 percent to nearly 100 percent of the total annual precipitation in the State. The average at Lamberton is about 82 percent (23).

Topography

Most of the State has been likened to a low plateau at the head of the Mississippi River with an average elevation of 1,200 feet above sea level (84). The roughest topography is to be found in the northeastern part of the State with the highest point in the Misquah Hills in Cook

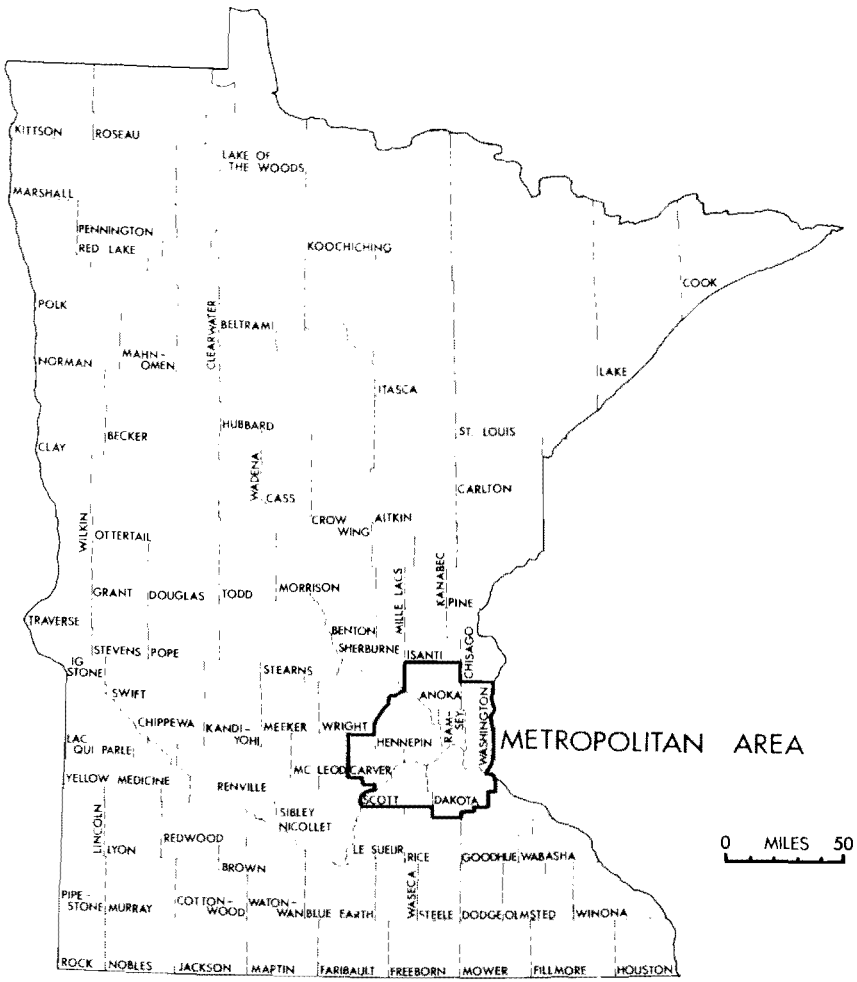


FIGURE 16. COUNTIES OF MINNESOTA (23)

County at 2,230 feet and the lowest point not far away at the surface of Lake Superior at 602 feet. Other high areas include the morainic hills near the headwaters of the Mississippi River and the southwestern corner of the State where elevations approach 2,000 feet. Low areas are found along the Mississippi River which leaves the State at about 630 feet elevation, the Red River of the North which enters Canada at about 750 feet, and the area extending from Mankato northeastward through the Metropolitan Area to Pine County which is mostly below 1000 feet. In effect, the State consists mostly of level to rolling prairie or forest land interspersed with irregular areas of glacial moraines with hills rising 50 to 300 feet above the surrounding land.

At Hibbing, the meeting point of the major drainage divides of the State (Figure 17) surface waters may flow either northward via the Souris-Red-Rainy River basin into Hudson Bay, eastward into Lake Superior and the Great Lakes, or southward into the Mississippi River and finally to the Gulf of Mexico. Despite the fact that considerable areas of North Dakota, Wisconsin, and Canada are tributary to the western, eastern, and northern boundary waters, very little water enters Minnesota through streams rising in other States.

Geology

Glaciation has had a major influence on the land surface features of the State. Glacial deposits cover most of the State. Outwash plains, some buried and others pitted with lakes, are to be found in many areas. The buried outwash sand and gravels constitute the principal source of ground water from glacial drift deposits. Glaciation was also responsible for creating many of the depressions that now constitute the State's several thousand lakes, (84).

The erosive action of wind and running water has also influenced the State's land surface features. The extensive sand plains located north of the Twin Cities are the result of such action on the glacial sand and gravel deposits (84).

The State is underlain by a series of Precambrian igneous and metamorphic rocks. A thick series of sedimentary rocks (limestones, sandstones, shales, and dolomites) fill a huge trough in the old Precambrian rocks in the eastern and southeastern parts of the State. Up to 500 feet of Cretacious shales and sandstones cover the eroded surface of the Paleozoic sediments and basement Precambrian rocks in the southwestern and western parts of Minnesota. Remnants of Cretaceous strata also overlie the Paleozoic rocks in parts of southern and southeastern Minnesota (84).

Population

Minnesota's population was estimated at 3,576,000 in 1966 by the Section of Vital Statistics of the Minnesota Department of Health. This represented an increase of 14,000 over the 1965 estimate and 162,132 over the 1960 Census population. Waelti (85) has predicted that the State's population will be in the range of 3,813,000 to 4,799,500 in the year 1980 and will increase to 4,700,000 by the year 2000, and 5,917,000 by the year 2020. His population growth curves shown in Figure 18 indicate

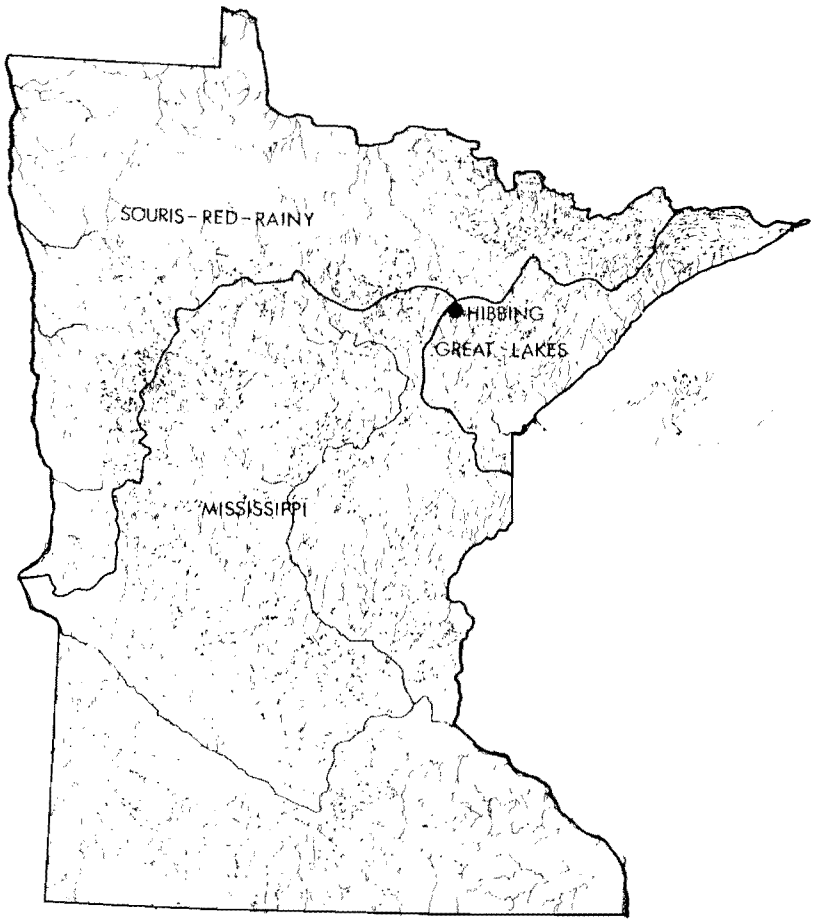


FIGURE 17. MAJOR DRAINAGE DIVIDES OF MINNESOTA (23)

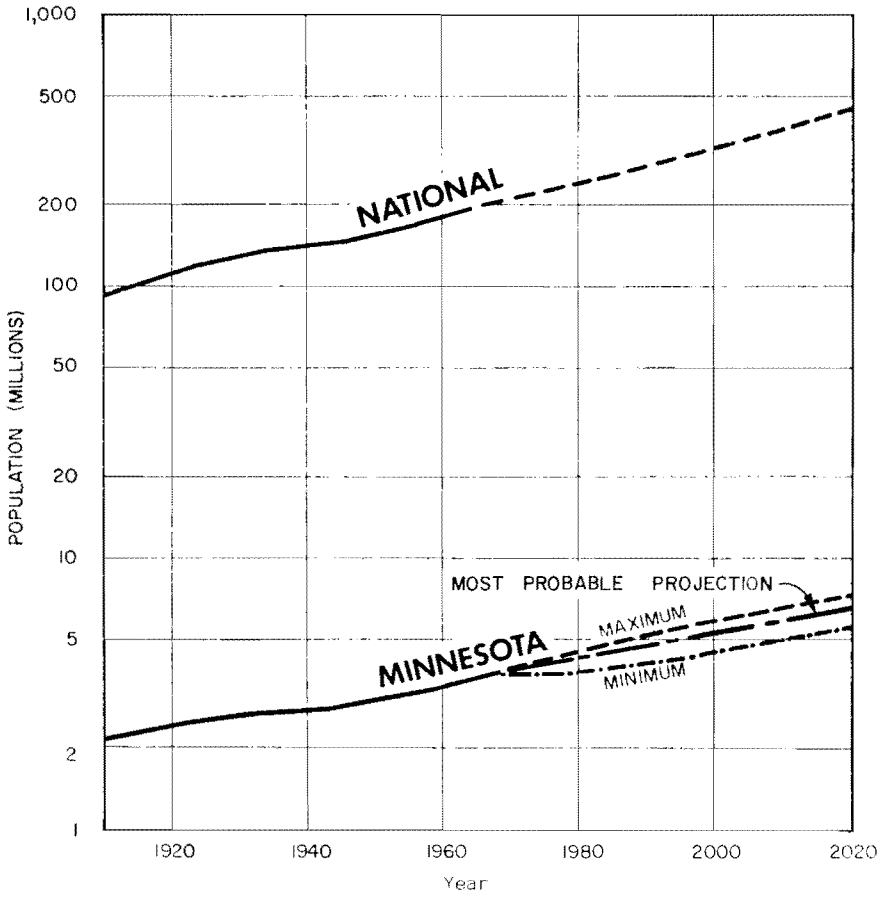


FIGURE 18. POPULATION GROWTH AND PROJECTION CURVES FOR MINNESOTA AND THE UNITED STATES OF AMERICA (85)

parallel rates of growth for the State and the nation from 1900 through 1960 and his expectation that this trend will be continued (85).

The State is one of the most metropolitanized States of the North Central United States with nearly one-half of its population centered in the seven county Metropolitan Area (Figure 19). The population of the Metropolitan Area in 1966 was estimated at 1,690,798 or 47.3 percent of the State's population. This represented an increase of 165,471 or 10.8 percent over the 1960 Census figure, and is the largest regional increase in the State. Projections of the Metropolitan Planning Commission indicate that 50 percent of the State's population will be living in the Metropolitan area in 1970 and this will rise to 68 percent or 4,000,000 people in this seven county area by the year 2000.

A substantial rural-urban shift has been noted in the State's population as evidenced in Table 5. While the urban population increased at the rate of 2 percent per annum over the period 1960 to 1965, the rural non-farm population increased at a rate of 1.2 percent per annum and the rural farm population declined at a rate of about 4 percent annually. Forecasts indicate that Minnesota will be 70 percent urban by 1970 and well over 80 percent urban by 1980 (7).

Table 5

Percentages of Minnesota Population
Urban and Rural, 1850 to 1965 (7)

Year	Percent	
	Urban	Rural
1850	0.0	100.0
1860	9.4	90.6
1870	16.1	83.9
1880	19.1	80.9
1890	33.8	66.2
1900	34.1	65.9
1910	41.0	59.0
1920	44.1	55.9
1930	49.0	51.0
1940	49.8	50.2
1950	53.9	46.1
1960	62.2	37.8
1965	64.3	35.7

Economic Activities

Mining, manufacturing, forestry and wood-using industries, fisheries, agriculture, and outdoor recreation are among the major economic activities in the State with some relevance to water resources management.

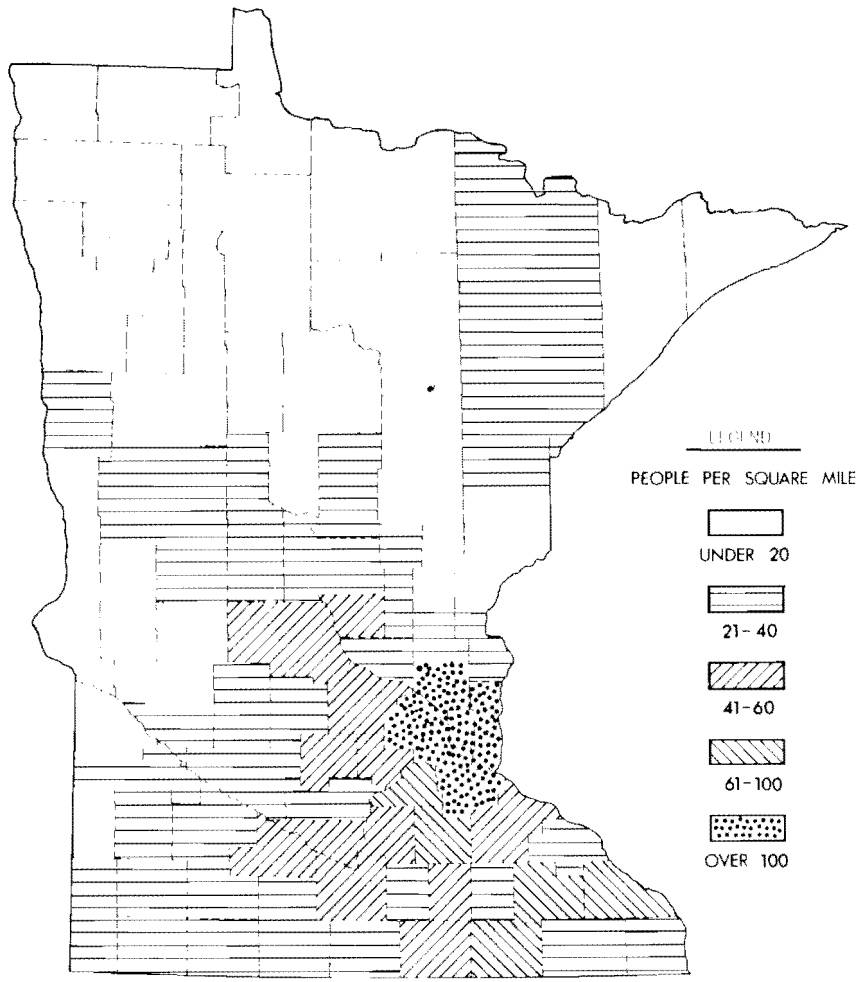


FIGURE 19. POPULATION DENSITY IN MINNESOTA IN 1960 (25)

Mining. Minnesota, with the largest deposits of iron ore in the United States and some of the largest in the world, produces 61 percent of the nation's supply. Iron ore accounts for about 91 percent of the State's total value of mineral production (23).

Better iron ore enriching processes and the dwindling supplies of high grade ores have led to the mining of low grade ores, such as taconite, in increasing quantities in recent years. Minnesota now has a taconite concentrate capacity of 32 million tons and these concentrates comprised 48 percent of all iron ore shipments in 1967 (23).

Other minerals mined in the State include clay, manganiferous ore, marl, stone, sand, gravel, and limestone. The total value of Minnesota's mineral production was approximately $519 million in 1967.

Manufacturing. By the measure of "value added", food processing and machinery manufacturing are the State's most important manufacturing industries. The value added by the food processing industry in 1963 totaled $588 million while machinery manufacturing, other than electrical, totaled $482 million. By far the greatest increase in both absolute and relative terms has been in machinery including both electrical and non-electrical types. Other important manufacturing industries include paper, chemicals, and stone and glass products (23).

The Twin Cities are the center of the State's manufacturing industry. Other areas with major manufacturing industries include many of the southeastern counties, and St. Louis, Carlton, and Koochiching counties in the northeast. The trend towards increased manufacturing activity is likely to continue (23).

Forestry and wood-using industries. In addition to the commercial timber produced, Minnesota's forests are of economic significance for their value in watershed protection and conservation, as game and wildlife habitats, and as tourist attractions.

Forested acreage has reduced from 31.5 million acres during the pioneering days to about 19 million acres today. Better forestry practices have resulted in greater annual timber growth over the past 30 years despite a 3 percent decrease in total forested acreage. About 20 percent of the commercial forest land in the State is owned by Federal agencies. Only Michigan owns more forest land than the State of Minnesota (23).

Timber-oriented industries employed about one-fifth of the population in 1958. Pulpmills are the most rapidly growing of the State's wood-using industry and employed 11,500 people in twelve plants in 1958. The output of timber production has remained relatively constant over the past twenty-five years (23).

Fisheries. Commercial fishing is carried on in the international, interstate, and inland waters. Lake Superior, Lake of the Woods, and Rainy and Namakan lakes are examples of the major international commercial fishing waters. Herring and smelt are the main fish caught in Lake Superior while other fish such as tullibee, yellow pike, and burbot are

the main catches in the other lakes. Approximately 3.4 million pounds of fish valued at over $269,000 were removed from these lakes in 1966. The Wisconsin Boundary Waters yield over 3/4 million pounds of fish annually while rough fish removed from inland waters amount to 10 million pounds annually. The annual value of commercial fishing between 1960 and 1966 has fluctuated between $200,000 and $300,000. Eleven fish wholesaling and processing plants produced $97,000 worth of products in 1965 (23).

Sport fishing is one of the main attractions of Minnesota's $300 million tourist industry. Sport fishermen reportedly spend about $100 million annually on their fishing activities with about 30 percent of this being "new" money brought in by visitors. Lake trout, walleye, bass, panfish and northern pike are among the more abundant sport fish. The State's lakes yield an average of 16 pounds of fish per acre of water surface annually with some lakes achieving 75 pounds per acre (85).

Agriculture is one of the State's leading industries with total receipts of $1.4 billion in 1964. Minnesota ranks fifth in the nation in total cash farm income; first in the output of butter, non-fat dry milk, sweet corn for processing, and oats; second in milk cows, turkeys, hay, and sweet clover seed production; and third behind New York and Wisconsin in milk production. Corn, hay, oats, and soybeans are the main harvested crops (23).

Though south central and southwestern Minnesota contain the highest proportion of high quality cropland, the best yields occur in the southeast where rainfall is highest (23). Irrigation has been limited to a small portion of the State's land, mostly sandy soils in the east-central region, totaling some 36,000 acres in 1961. The trend in recent years, however, indicates a rapid increase in the use of irrigation and one that is likely to continue (11).

Minnesota's agricultural industry has been experiencing many other changes in recent years, in addition to greater irrigation use, with implications on the State's water resources. While the number of farms is decreasing, farm sizes are increasing (Figure 20). The practice of using cattle feed lots is also increasing and bringing with it waste disposal problems.

Outdoor recreation. Growth in population, leisure time, income, and mobility has resulted in the rapid growth of outdoor recreation in the State which is likely to continue. It is estimated that Minnesotans spent 111.5 million person days on a total of 11.3 million occasions at major outdoor recreational activities in 1960. These figures are predicted to increase to 16.8 million and 230.6 million, respectively, in 1976 (86).

Water is the prime factor in most forms of outdoor recreation such as fishing, pleasure boating, swimming, aesthetic enjoyment and skiing.

Outdoor swimming, boating and canoeing, and fishing rank in that order behind auto pleasure driving as the major outdoor recreational activities in which Minnesotans participate (86). Minnesota's many lakes,

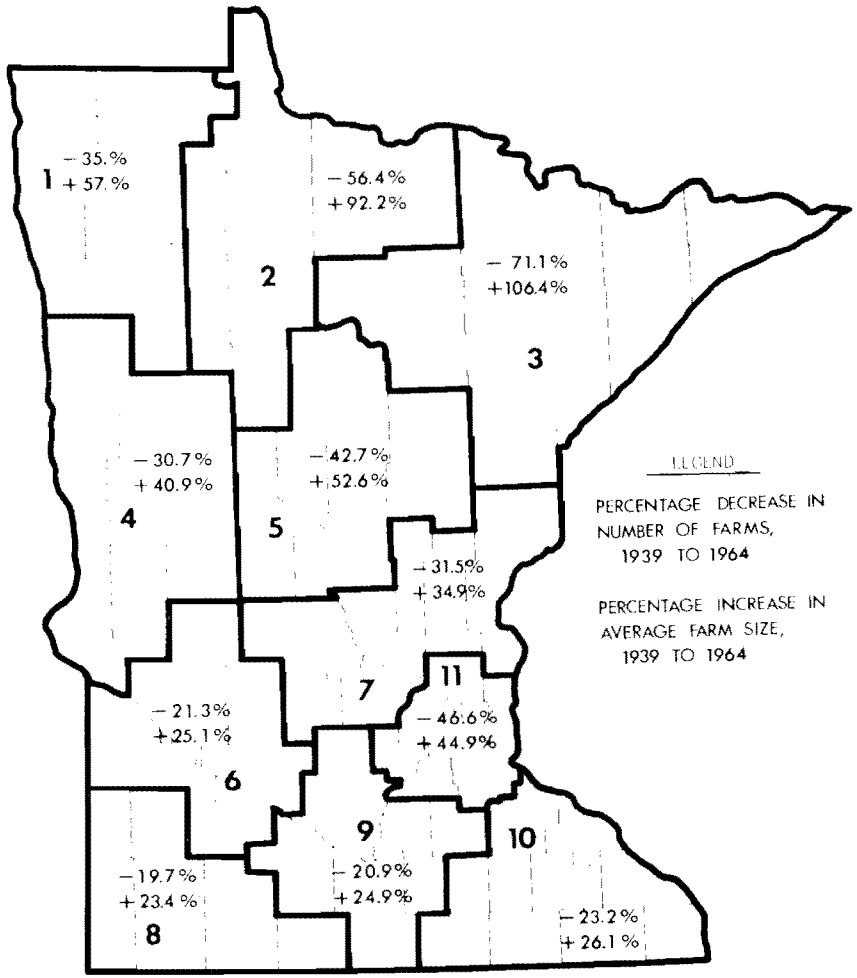


FIGURE 20. REGIONAL CHANGES IN NUMBER AND SIZE OF FARMS IN MINNESOTA, 1939-1964 (23)

because of their accessibility and suitability, are of primary importance in the State's recreation picture (23). The rivers also play an important part that is likely to become more so in the future as Figure 21 demonstrates (86).

Outdoor recreation also plays an important role in the attraction of money to the State as can be seen from the earlier reference to an estimated $30 million annually attracted by sport fishing.

II. SURFACE WATER

Mention has been made earlier in this chapter to the vastness of these resources. Figure 17 shows the division of the State by drainage divides into three major basins -- the Souris-Red-Rainy Basin discharging northward into the Hudson Bay; the Great Lakes Basin discharging eastward into the St. Lawrence River; and the Mississippi Basin discharging southward into the Gulf of Mexico. The approximate percentage of the State in each of these basins is given in Table 6.

Reference has also been made to the fact that the State's many thousands of lakes and 25,000 miles of streams constitute 6.1 percent of the nation's water surface area, ranking it the fourth largest in the nation.

Table 6

Percentages of Minnesota's Area in Major River Basins (23)

Basin	Percentage of State's Area	
Mississippi River		58
Mississippi	56	
Missouri	2	
Souris-Red-Rainy Rivers		34
Roseau	2	
Red River of the North	19	
Boundary Waters	13	
Great Lakes		8
Total		100

Lakes

The surface area of lakes in the State total 4,059 square miles or 4.8 percent of the State's area. There are 15,291 lake basins larger than 10 acres and five of these are listed among the 16 largest inland fresh water lakes in the United States. Table 7 lists the areas of a

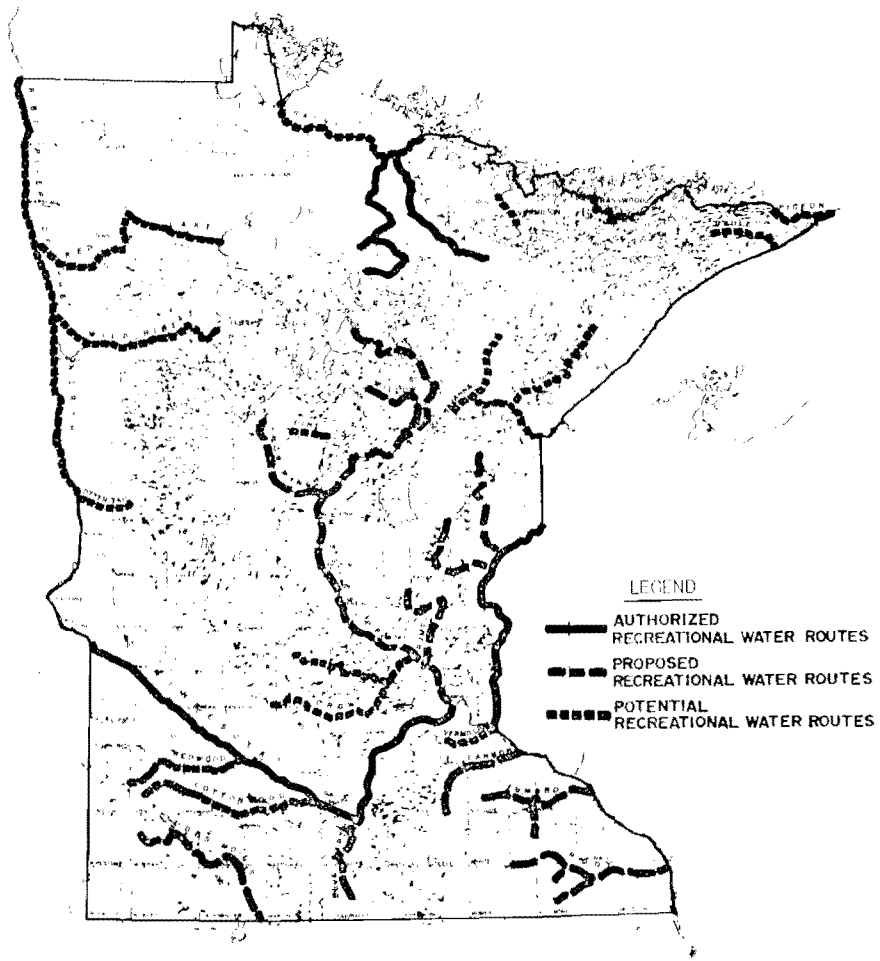


FIGURE 21. MINNESOTA'S RECREATIONAL RIVERS AND STREAMS (86)

Table 7

Areas of Major Minnesota Lakes (23)

Lake	Area (Acres)
Wholly in Minnesota:	
Red - Upper and Lower	274,990
Leech	160,540
Mille Lacs	133,000
Winnibigoshish	114,800
Pokegama	22,080
Whitefish Chain	15,200
Otter Tail	14,745
Boundary Waters Lakes:	
Pepin	27,200
St. Croix	9,600
Big Stone	12,500
Traverse	16,200
Lake of the Woods	950,400
Rainy	22,800
Superior	1,400,000

number of the most important lakes, the locations of which can be seen in Figure 22.

Most of the lakes are to be found in the northeastern Border Lakes Region and the Central Lake Region. The distribution of lakes elsewhere in the State is sparse. With the exception of a few, the lakes are shallower than 100 feet with many of the larger lakes being quite shallow. The deepest lakes are the 240 feet deep Lake Saganaga on the Canadian border, the 226 feet deep Lake Gambimichigami in Lake and Cook counties, and the 210 feet deep Mountain Lake in Cook County. Lake Elmo, depth 140 feet, is the deepest in the vicinity of the Twin Cities (23).

The lakes provide natural storage during periods of heavy runoff after major storms. They later release stored water to streams thus equalizing stream flow but resulting in a gradual lowering of lake levels. In the interest of recreational use, lake level fluctuations have been controlled by the use of dams to reduce or stop the natural discharge into streams. Less water is then available in streams to facilitate navigation, the dilution of wastes, power development, and water supply uses.

A number of man-made lakes have been created by damming rivers in the interest of flood control and navigation. The major ones, including the six on the headwaters of the Mississippi, are indicated in Figure 22. A description of these and other development works of the U. S. Army Corps of Engineers are to be found in reference (87).

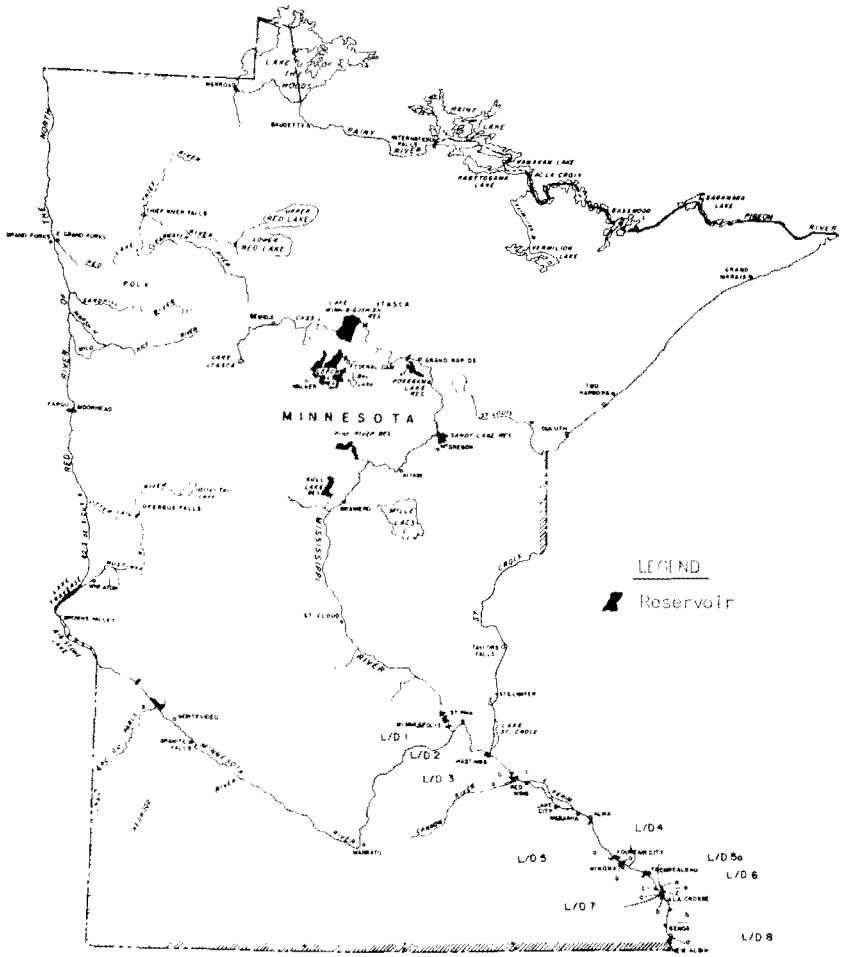


FIGURE 22. MAJOR RIVERS AND LAKES IN MINNESOTA (87)

Streams

Figure 17 depicts the myriad of streams that are tributary to major rivers in Minnesota.

In the southeastern portion of the State the streams flowing from the prairies to the Mississippi River, 300 to 600 feet below, have cut deep gorges in the easily erodible soils, and soft bedrock limestones and sandstones. These streams are flashy due to the steep channels and relatively high rainfall averaging 32 inches annually. Soil erosion and silting problems are serious and the high discharges and velocities sometimes threaten damage to bridges (23).

Slowly meandering streams and shallow valleys characterize the northwestern portion of the State. Rainfall is relatively low in this area and, combined with the high evapotranspiration and seepage losses from the gently sloping, poorly drained land, result in relatively low runoff (Figure 25). Runoff from the melting snows and warm spring rains in the southern part of the north flowing streams causes spring floods in the still frozen, ice jammed northern reaches of these streams. The Red River of the North and the Little Fork and Big Fork Rivers are very much subject to this type of flooding (25).

In north-central Minnesota, where the forest cover is heavy, the land slopes gently, the soils highly permeable, and the storage capacity of lakes, marshes, and reservoirs high, the streams have moderate total runoff with sustained dry-weather flows and no serious flood problems (25).

The watersheds of southwestern Minnesota are generally gently rolling to hilly land, highly cultivated and almost devoid of natural lakes and undrained swamps. The streams tributary to the Minnesota River are subject to severe flooding with considerable damage to urban development in the flood plains (23).

The flow characteristics of many streams have been altered by dams constructed throughout the history of the State for a variety of reasons. Literally hundreds of these were built by early settlers to augment flows in smaller streams used to transport logs. Others provided power for saw mills, flour mills, and paper mills and yet others for flood control and navigation improvement. The number of these dams that are still functioning is reportedly unknown (25).

The watershed units comprising the three major river basins of the State are shown in Figure 24, while Figure 25 depicts the average discharges of the principal rivers. For more detailed information on river discharges see (23; 84; 88) and the U. S. Geological Water Supply Papers.

The Mississippi River. Following an almost semi-circular course for 370 miles from its source in Lake Itasca at an elevation of 1,463 feet above sea level to Brainerd (Figure 22), the Mississippi River cuts through the western end of the Mesabi iron range at Grand Rapids and passes the Cuyuna iron range near Aitkin. Beyond Brainerd it travels south and southeast for 150 miles to the Twin Cities of St. Paul and

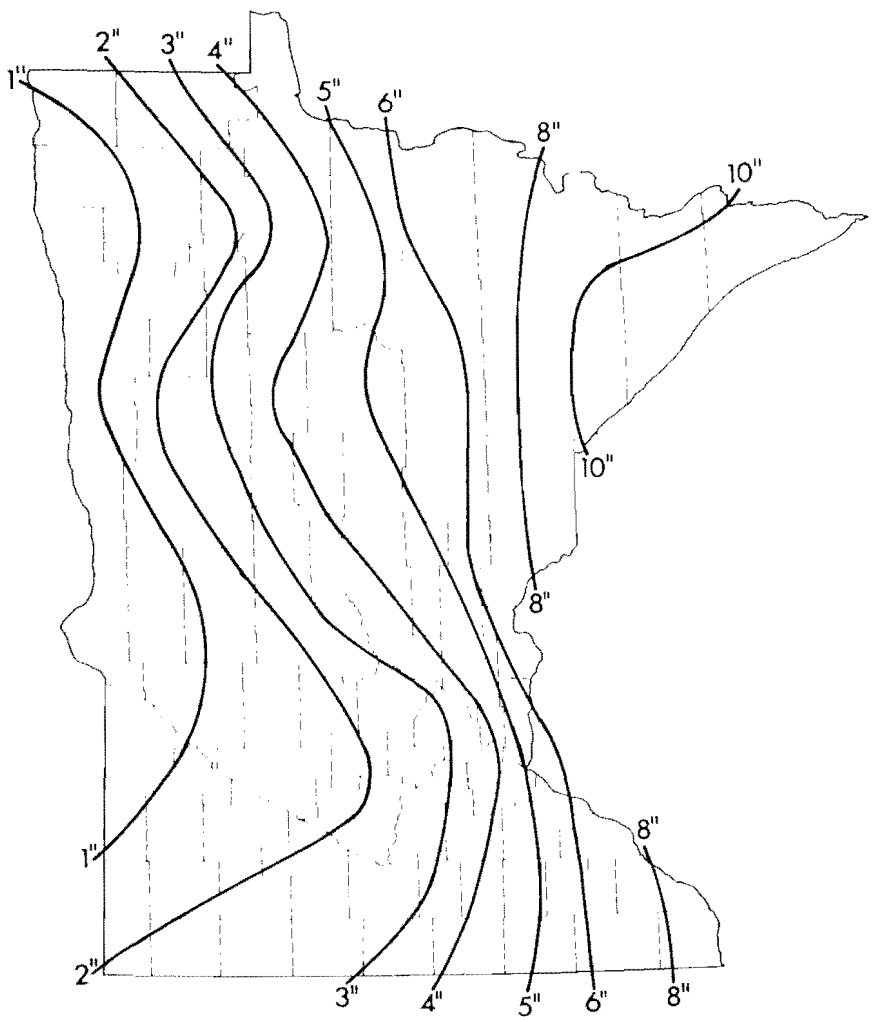


FIGURE 23. AVERAGE ANNUAL RUNOFF IN MINNESOTA (23)

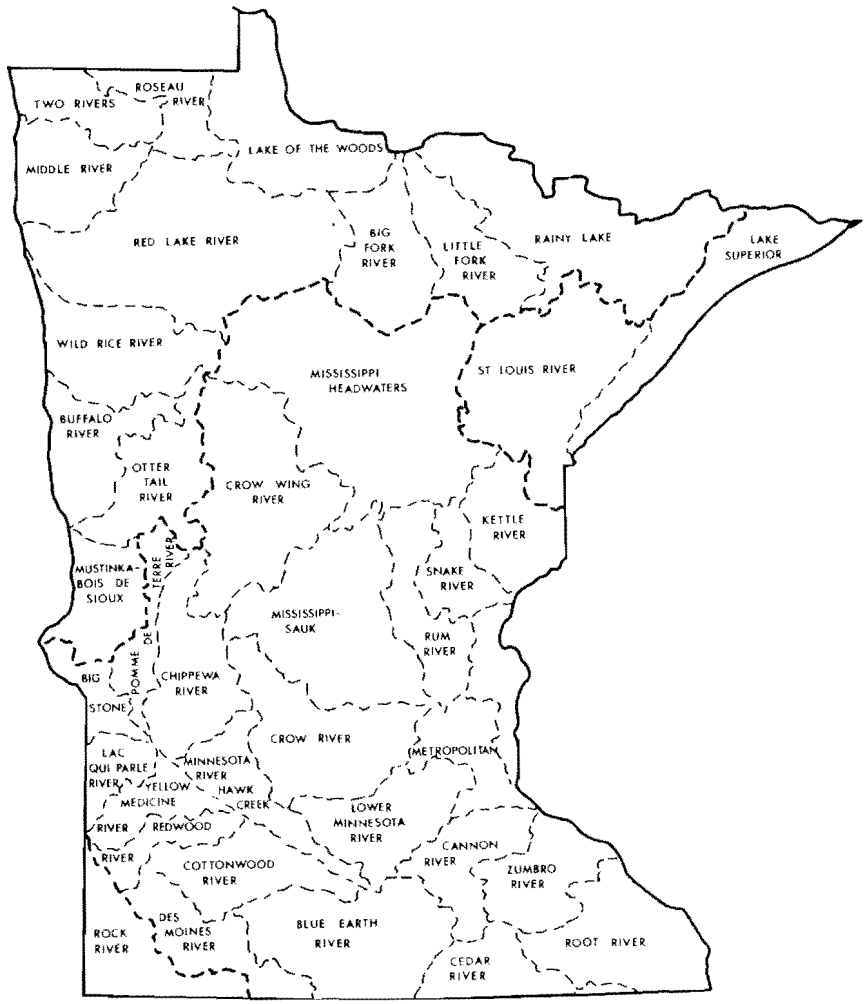


FIGURE 24. WATERSHED UNITS IN MINNESOTA (24)

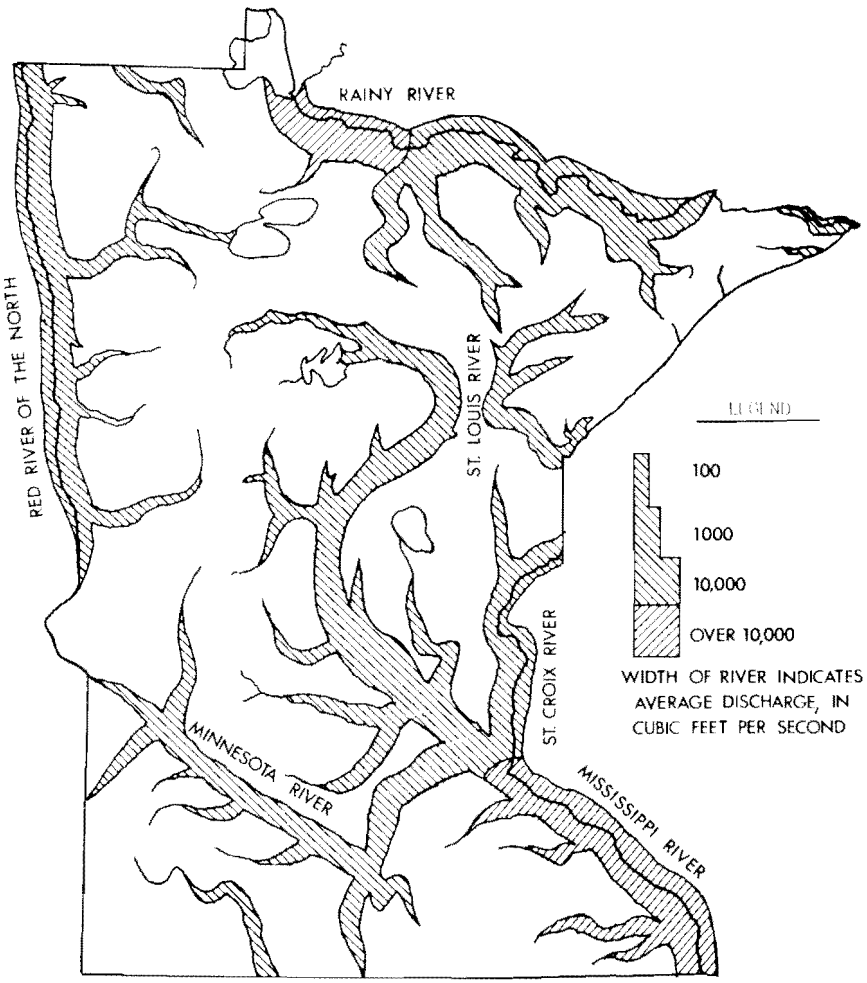


FIGURE 25. AVERAGE DISCHARGE OF THE PRINCIPAL RIVERS IN MINNESOTA (23)

Minneapolis where its major tributary, the Minnesota River, enters it. The St. Croix River, another large tributary, joins it below St. Paul, and below this junction the Mississippi River constitutes the Minnesota-Wisconsin boundary. Flowing through bluffs 200 to 600 feet high it enters Lake Pepin which is one to two miles wide and about 22 miles long. By the time the Mississippi River leaves the State at an elevation of 630 feet it has already accounted for 57 percent of its total fall to the Gulf of Mexico and drained 65,000 square miles of land of which 45,000 are in Minnesota, and the remainder being in Wisconsin, South Dakota, and Iowa (84).

Natural regulation of stream flow provided by porous soil, heavy vegetative cover, the many lakes and marshes combine with the artificial control by the six headwater reservoirs to make severe flooding above the Twin Cities an infrequent occurrence. Most flood damage occurs to farms in the vicinity of Aitkin; the industrial and residential developments in the flood plains at St. Paul and South St. Paul, and to similar property near Winona.

The river is the source of essentially the entire municipal water supply of the Twin Cities. Generally adequate for this purpose, the river flows only barely exceed demand at times of extreme low flow in summer months when water use is also at its peak (84).

Hydro-electric power is provided for paper mills at Grand Rapids, Little Falls, Brainerd, and Sartell, and by public utilities and industries below Bemidji Lake and at Little Falls, Blanchard Rapids, St. Cloud, St. Anthony Falls and Lock and Dam No. 1 just above the junction with the Minnesota River (84).

Navigation has been improved on the Mississippi by the construction of nine locks and dams used to maintain a channel of minimum depth 9 feet from a point above St. Anthony Falls to the southern boundary of the State (84). Recreational boating and fishing both benefited from the improved channel.

The river is a major flyway for migratory waterfowl and provide excellent hunting for virtually all species of duck and geese found in the central United States. Many residents also receive substantial incomes from the trapping of fur-bearing animals in the river bottoms.

The Minnesota River. This largest of tributaries of the Mississippi River in the State of Minnesota drains an area of about 16,900 square miles, all but 2,000 of which are in Minnesota. From its source in Big Stone Lake, the river flows 224 miles southeastward to Mankato then northeastward for 106 miles to its junction with the Mississippi at Fort Snelling. The valley is generally deep with high bluffs on either side of the river. The present channel meanders widely across the alluvial deposits in the valley. The gradient of the river bed averages 0.8 feet per mile and is steepest at 11 feet per mile in the vicinity of Granite Falls. Below Shakopee the water level is approximately the same as maintained at Lock and Dam No. 2 on the Mississippi near Hastings (23).

The tributaries of the Minnesota River downstream of Mankato are mainly 10 to 30 mile long creeks flowing through deeply eroded valleys. Rush River and High Island and Sand Creeks are the only large streams. Upstream of Mankato the tributaries from the south are steep, sometimes producing flash floods of greater flow than the mainstem. The tributaries from the north also carry large volumes of water but generally rise slower and have peaks of longer duration (23).

Floods were frequent in the valley, occurring biennially above Mankato and almost annually below that city, prior to the construction of the Big Stone Lake-Whetstone River and Lac Qui Parle flood control works in 1937 and 1940, respectively. The floods, mainly local in character, damaged cultivated lands, roads, and bridges. The Big Stone Lake works have reportedly never fully served their flood control purpose and have instead been used chiefly to maintain lake levels for recreational purposes. The Lac Qui Parle project has, however, been operated to reduce flood stages substantially at and considerably downstream of Montevideo (84).

The river is utilized for water supply at Granite Falls only, and for hydro-electric power at Minnesota Falls and Granite Falls (84).

The St. Croix River for most of its length constitutes the boundary between Minnesota and Wisconsin. Rising at an elevation of 1,010 feet above sea level on the Lake Superior-Mississippi River divide some 20 miles from the lake, it flows southwest and then south until it enters the Mississippi River below Hastings.

The gradient is steepest in the lower St. Croix River in the 38 mile reach above Taylors Falls where the total drop is 100 feet. The gradient is a mere 0.5 feet per mile between Taylors Falls and Marine below which water stages are affected by the backwater from Lock and Dam No. 3 at Red Wing on the Mississippi River. The channel widens to form Lake St. Croix with an average width of about 3000 feet between Stillwater and the mouth of the river. The principal tributaries are the Namekagon, Yellow, Apple, and Willow Rivers in Wisconsin and the Tamarac, Kettle, Snake, and Sunrise Rivers in Minnesota.

The St. Croix River is relatively undeveloped and is free flowing from a few miles west of Gordon, Wisconsin to Taylors Falls, Minnesota. It abounds in game fish, has two State Parks and an Interstate Park along its banks, and is of considerable recreational importance and potential.

Under the Wild and Scenic Rivers Act of 1968, Public Law 90-542, about 200 miles of the Upper St. Croix River and its tributary the Namekagon, including 75 miles adjoining Minnesota's eastern border above Taylors Falls, have been included in the National Wild and Scenic Rivers System. The river corridor in this area is to be preserved for canoeing, hiking and other outdoor recreational activities.

The Red River of the North. Formed by the coming together of the Otter Tail and Bois de Sioux Rivers near Breckenridge, Minnesota, the Red River of the North flows almost due north along the Minnesota-North Dakota boundary until it crosses into Canada. It continues northward in

Canada into Lake Winnipeg from which its waters flow into Hudson Bay. The valley is narrow at its southern end but widens downstream to about 60 miles until it all but loses its identity on the Minnesota side north of the Red Lake River. The stream has an average fall of about 0.5 feet per mile from its 1000-foot elevation north of Lake Traverse to its 750-foot elevation at the Canadian boundary. Of the 39,300 square miles of the United States drained by the Red River, 17,800 are in Minnesota, 20,530 in North Dakota and 990 in South Dakota (23).

About one-half of the watershed is within the bed of the glacial Lake Agassiz. The fertile soils developed from the lake sediments have made the valley famous for its agricultural products.

The principal tributaries in Minnesota are the Pelican, Buffalo, Wild Rice, Red Lake, Snake, Two Rivers, and Roseau rivers. Those in North Dakota are Bois de Sioux, Wild Rice, Sheyenne, Goose, Park and Pembina rivers.

The Rainy River. Characterized by many irregularly shaped lakes and short connecting streams through forested rocky country, the Rainy River drains 4,489 square miles in Minnesota and another 10,010 square miles in Canada. The watershed slopes in a general northwesterly direction at an average of 12 to 15 feet per mile. Elevations in the watershed range from about 2000 feet above sea level in the hills south of Saganaga Lake to about 1,060 feet at Lake of the Woods (23).

The Border Lakes Region besides being of great scenic significance is also of historic importance because of the Voyageurs Route. The Federal Government is considering the preservation as a National Park of an area east of Black Bay of Rainy Lake, including the Kabetogama Lake and Peninsula, Rainy Lake south of the Canadian border and east of Black Bay, and Namakan Lake (23). The watershed also includes what is known as the Boundary Waters Canoe Area (Figure 26) which provides the "best canoeing in the Nation" and is a haven for photographers, naturalists, ornithologists and sightseers (23, p. 202).

The St. Louis River flows 160 miles and falls about 1,065 feet from its source in Seven Beaver Lake to its mouth on Lake Superior. The river has gradients in excess of 25 feet per mile above Two Rivers and then falls 118 feet in 86 miles to Cloquet where hydroelectric development creates a head of 70 feet. The fall is moderate between Cloquet and Thomson after which the river follows a deep, narrow, rocky gorge, falling 500 feet to Lake Superior. The river valley varies in depth from 10 to 30 feet in the upper part of the watershed above Floodwood beyond which it gets gradually deeper and wider to Thomson. The larger tributaries are the Whiteface and Cloquet Rivers, 122 and 80 miles long, respectively, and with a combined drainage area of 1400 square miles (23).

Reservoirs in the headwaters of the St. Louis, Whiteface and Cloquet Rivers provide artificial regulation of stream flows in the mainstem of the St. Louis River.

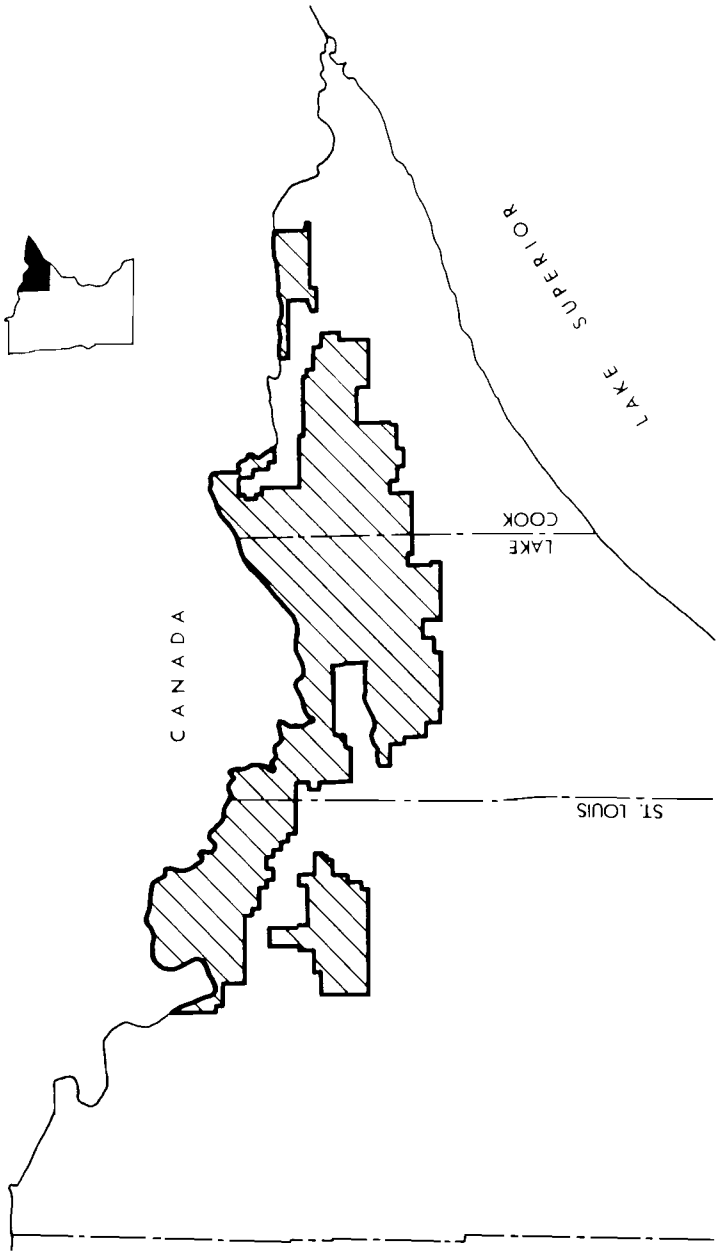


FIGURE 20. BOUNDARY WATERS CANOE AREA, SUPERIOR NATIONAL FOREST, MINNESOTA (83)

III. GROUND WATER

Despite the fact that ground-water sources in 1960 provided about 60 percent of the water withdrawn for various uses in the State of Minnesota, the available processed information on ground-water resources is somewhat sketchy and inadequate. Particularly noticeable by its general absence is information on the hydraulic characteristics - coefficients of storage, permeability, and transmissibility - of the aquifers or water-bearing formations.

The *coefficient of storage* of an aquifer is the volume of water released from, or taken into, storage per unit of surface area of the aquifer per unit change in hydraulic head normal to that surface. It is a dimensionless number.

The *coefficient of permeability* is the volume of water that will flow in gallons per day (gpd) through a unit cross-sectional area of aquifer material in unit time under a hydraulic gradient of unity (1 foot head per foot length of flow). It is usually expressed in gallons per day per square foot (gpd/sq. ft.).

The *coefficient of transmissibility* is the rate of flow of water through a vertical strip of an aquifer of unit width and full saturated thickness of the aquifer under a hydraulic gradient of unity. It is usually expressed in gallons per day per foot (gpd/ft) and is equivalent to the product of the coefficient of permeability and the saturated thickness of the aquifer.

The coefficient of storage indicates the quantity of water that can be removed from an aquifer while the coefficients of permeability and transmissibility indicate the rate at which water travels through an aquifer and, therefore, the rate of removal. These coefficients must be known in order to determine the potential yield of aquifers and for proper comparisons among aquifers. It is very inadequate simply to indicate ranges of well yields in gallons per minute (gpm) for various areas, as reported in the literature, since these by themselves are not indicators of aquifer potential. The fact that wells in a particular area yield an average of 20 gpm may simply mean that these wells are designed to meet the limited household needs of a rural farm population and not that the aquifer isn't capable of much higher sustained yields. On the contrary, properly designed large wells in such an area may possibly yield much more than the 500 gpm indicated for other areas, and with less drawdown or lowering of the water level in the wells. A mere indication of well yields can, therefore, be misleading as well as an inadequate measure or indicator of aquifer potential. The United States Geological Survey (USGS) has recently begun the preparation of a Hydrologic Investigations Atlas incorporating information on the storage coefficient, permeability and transmissibility of aquifers. However, only a few of the 39 watersheds established by the Minnesota Department of Conservation (84) have so far been covered. In the absence of better information with which to examine the State's ground-water resources, references to well yields must be considered in the light of the above limitations.

The Minnesota State Planning Agency has chosen to divide the State into four ground-water "provinces" based mainly on the dominant geologic environment, in most cases the type of glacial materials (23). These provinces are depicted in Figure 27.

The Southeastern Province. The water-bearing characteristics of the geologic units of this region are shown in Table 8. The most developed aquifers are in the consolidated bedrock units that lie in two structural basins - one in the southern part of the province and the other in the Twin Cities area. Overlying the bedrock is a mantle of gray drift except in the extreme southeast where a thin layer of silty sand covers the bedrock. The drift ranges in thickness from 100 to 200 feet, contains irregularly shaped sand grains and at its base sandy materials fill bedrock valleys.

This province has the largest potential ground-water yields in the State and can adequately meet present and foreseeable needs (23). Two of the four water-bearing bedrock formations, the Jordan-Prairie du Chien, and the Mount Simon-Hinckley of the Twin Cities Artesian Basin (Table 9) yield as much as 3000 gpm to wells ranging in depth from 400 to 1800 feet High yielding sand and gravel aquifers are also to be found in some of the deposits overlying the bedrock. Water quality is generally good with treatment required only for the reduction of hardness and iron (23).

The unconsolidated sediments of the Mississippi River valley, sometimes 200 feet thick, contain sand and gravel that have yielded more than 1000 gpm to single wells. In the Minnesota River valley, however, the unconsolidated sediments are generally fine-grained and yield water to wells at slow rates. Buried outwash aquifers in this valley have produced good wells for industrial and municipal use. The alluvial terrace deposits extending along the St. Croix River at altitudes of up to 200 feet above the river level, and thickness of 150 feet have yielded up to 500 gpm to wells. The extension of these deposits into the pre-glacial channel in Chisago County has produced well yields exceeding 500 gpm. Alluvial deposits of more recent origin than the pre-glacial in the St. Croix valley are fine-grained and low yielding (23).

The St. Peter Sandstone with a maximum depth of 700 feet in Freeborn and Mower Counties is the source of many water supplies in the province. It is medium to fine-grained, and white to yellow in color. Loosely cemented, it is of high porosity. Its permeability or ability to transmit water is, however, low because of its fine-grained characteristic. It is used mainly for household, farm, and small industrial and municipal supplies. The water is very hard and its iron content high.

Below the St. Peter Sandstone lies the Prairie du Chien Group and Jordan Sandstone which are usually considered together because of extensive movement of water between them. Wells tapping these two geologic units are usually completed in the lower Jordan Sandstone, thus benefitting from water in both. The permeability varies throughout the Jordan Sandstone but well yields are generally high, reaching 3000 gpm (23).

Very little information is available on the Franconia and Galesville Sandstones lying below the Jordan, since very few wells have been completed

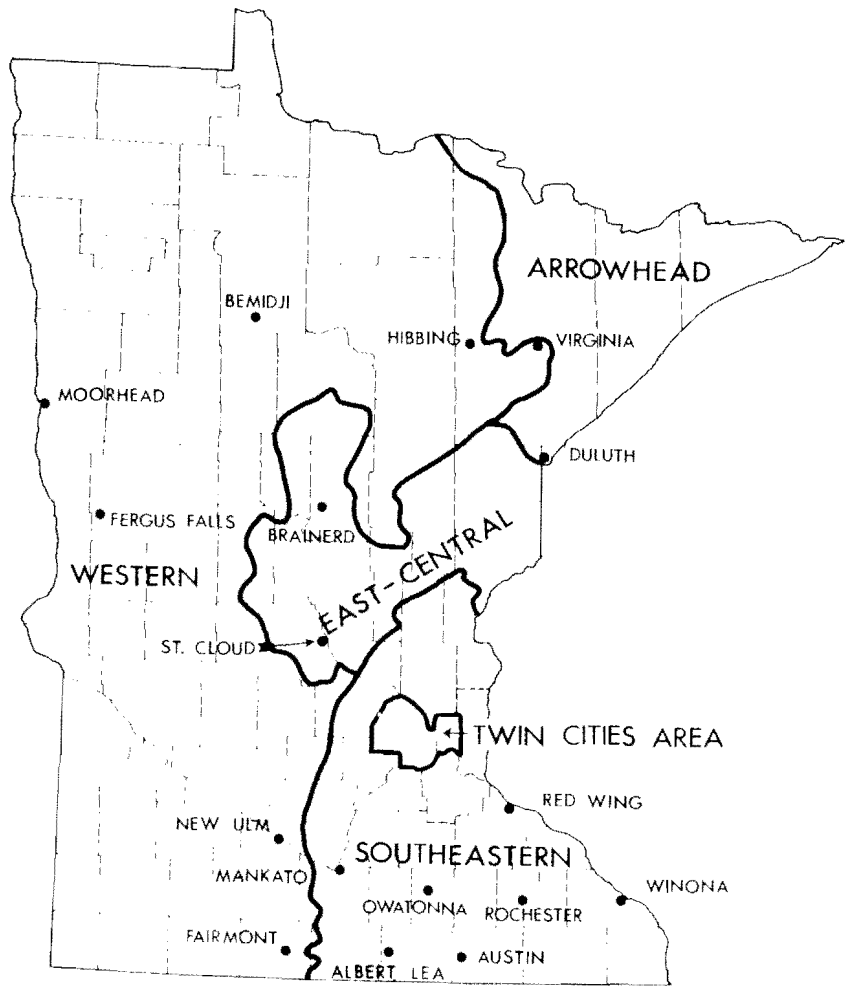


FIGURE 27. GROUND-WATER PROVINCES OF MINNESOTA (23)

Table 8

Water-bearing Characteristics of Geologic Units of the Southeastern Ground-water Province of Minnesota (23)

System	Rock Unit	Approximate thickness (in feet)	General lithology	Water-bearing characteristics
Quarternary	Recent	0 - 200	Alluvial clays, silts, sands, and gravels	Small to moderate yields from "fills" in glacial valleys
	Pleistocene	0 - 400	Thin to thick layers of calcareous clayey silt with gravel to to silty sand bodies; silty sand lake beds	Small to moderate yields from sand bodies in upper drift; moderate to large yields from drift "fill" in bedrock valleys
Cretaceous	Cretaceous	25 - 100	Sandy shale and impure sandstone	Low to moderate yields from sandstones
	late Mesozoic regolith	0 - 125	Sandy clay	Low yields
Devonian	Cedar Valley	130	Mostly limestone minor dolomite beds	Low to moderate yields
Ordovician	Maquoketa	70	Very calcareous shale	Low yields
	Dubuque	35	Interlayered limestone and shale	Low yields
	Galena	170	Limestone,dolomite-rich limestone and shaly limestone	
	Decorah	20 - 80	Blocky to fissle shale with sandy shale at base	Small yields from fractures
	Platteville-Glenwood	20 - 40	Shale-rich limestone with sandy siltstone and shale near base	Small yields from fractures & solution cavities
	St. Peter	90 - 150	Well sorted sandstone with siltstone & shale near base	Small to moderate yields
	Prairie du Chien	125 - 260	Two dolomitic limestone units separated by a sandstone unit which thickens to the SE	Moderate to large yields from fractures & sandy layers
Cambrian	Jordan	80 - 150	Well sorted sandstone	Large yields
	St. Lawrence	15 - 150	Dolomitic siltstone and sandstone	An aquitard
	Franconia	200	Well sorted sandstone with shale bed 20 thick 50' above base	Small to moderate yields
	Dresbach	300	Upper sandstone, siltstone & minor shale; lower well sorted sandstone	Moderate yields
Precambrian	Keewenawan	4000	Upper 200' of coarse-grain which become more shale-rich with depth	Upper part moderate yield, lower part undetermined
	Other PC	?	Volcanic rocks to 20,000' thick; plutonic rocks below	Undetermined

Table 9

Water-bearing Characteristics of Geologic Units in the Twin Cities Artesian Basin, Minnesota (23)

CLASS	FORMATION AND MEMBER	APPROX. THICKNESS (in feet)	DESCRIPTION	GRAPHIC COLUMN	AQUIFERS AND AQUITARDS
QUATERNARY	Undifferentiated glacial drift	0-400	Glacial till, outwash sand and gravel, valley train sand and gravel, lake deposits, and alluvium of several ages and several provenances, vertical and horizontal distribution of units is complex		Distribution of aquifers and aquitards is poorly known. Sand and gravel aquifers containing moderate to large amounts of water appear to be common in buried bedrock valleys.
ORDOVICIAN	Decorah Fm.	90	Shale, bluish-green to bluish-gray, blocky, thin, discontinuous beds of fossiliferous limestone throughout formation.		Aquitard (or bedrock). Small quantities of water available from fractures and solution cavities.
	Platteville Fm.	Up to 15	Dolomitic limestone and dolomite, dark gray, hard, thin bedded to medium bedded, some shale partings, can be divided into two units here.		
	Glenwood Fm.	Up to 5	Shale, bluish-gray to bluish-green, generally soft but becomes dolomitic and harder toward east.		Aquitard (or bedrock).
	St. Peter Ss.	150	Sandstone, white, fine- to medium-grained, well sorted, quartzose, locally iron stained and well cemented, rounding and frosting of grains is common, 5-50 feet of siltstone and shale near bottom of formation.		Aquifer zone (or bedrock). Small to moderate amounts of water available.
	Prairie du Chien Fm. — Shakopee Member	60	Dolomite, light brown to buff, thin to thick bedded, cherty, shale partings, commonly sandy and oolitic.		Aquitard (or bedrock).
	Prairie du Chien Fm. — New Richmond Memb.	0-30	Sandstone and sandy dolomite, buff, often recessive.		
	Prairie du Chien Fm. — Oneota Memb.	50-120	Dolomite, light brownish gray to buff, thin- to thick bedded, cherty.		Aquifer zone (or bedrock). Large quantities of water available. The most widely used source of ground water in the area.
CAMBRIAN	Jordan Ss.	90	Sandstone, white to yellowish, fine- to coarse-grained, massive to bedded, cross bedded in places, quartzose, commonly iron stained.		
	St. Lawrence Fm.	50	Dolomitic siltstone and fine-grained dolomitic sandstone, glauconitic in part.		Aquitard.
	Franconia Fm. — Reno Memb.	120	Sandstone, very fine grained, moderately to highly glauconitic, worm tubed in places.		Aquifer zone. Small amounts of water available.
	Franconia Fm. — Mahomanee Memb.	Missing			
	Franconia Fm. — Lunah Memb.	70	Interbedded very fine grained sandstone and shale, has a flaser contact.		Aquitard zone.
	Franconia Fm. — Birkmose Memb.	20	Glauconitic fine-grained siltstone and argillaceous, silty fine-grained sandstone (ripple-cross laminated).		
	Franconia Fm. — Woodhill Memb.	30	Sandstone, medium- to very fine-grained, cross bedded.		Aquifer zone. Moderate amounts of water available.
	Dresbach Fm. — Galesville Memb.	15	Sandstone, yellow to white, medium to coarse grained, poorly cemented.		
	Dresbach Fm. — Eau Claire Memb.	Up to 150	Sandstone, siltstone, and shale, gray to reddish brown, very heterolithic.		Aquitard
	Dresbach Fm. — Mt. Simon Memb.	Up to 200	Sandstone, gray to pink, medium- to coarse-grained.		Aquifer zone. Moderate quantities of water available.
	Unconformity				
KEWEENAWAN	Hinckley Ss.	Up to 200	Sandstone, buff to reddish, coarse grained.		
	Unconformity				
	'Red Clastics'	Up to 4,000	Silty feldspathic sandstone and lithic sandstone, fine-grained, probably also includes red shale.		
	Unconformity				
	Volcanic rocks	Up to 20,000	Mostly mafic lava flows but includes thin interbedded layers of tuff and breccia.		Aquifer zone.

in them. Preference is shown for the higher yielding aquifers above and below these sandstones. Indications are that these sandstones are recharged from the Jordan Sandstone in which the hydraulic head is higher.

The Mount Simon-Hinckley Sandstones, separated from the overlying rocks by the shale beds of the Eau Claire Sandstone, yield water at moderate rates, usually less than the Jordan-Prairie du Chien aquifer. The long term yield is also likely to be less, despite the greater thickness of the Mount Simon-Hinckley aquifer, because of its slower rate of recharge. The Hinckley Sandstone is not present in much of the southeastern province (23).

The Twin Cities Artesian Basin is shown in a generalized geologic and hydrologic cross-section in Figure 28. The potential of the glacial drift in this basin is relatively unexplored but likely to be most important in the bedrock valleys which are 50 to 450 feet deep. Sand beds and lenses found abundantly in the drift are heavily tapped by domestic wells in suburban areas.

The consolidated bedrock aquifers are generally fully saturated with water under pressure. The piezometric surface - imaginary surface to which the water levels in wells throughout an artesian or pressure aquifer would rise - of these aquifers are to be found above the tops of the bedrock units. The multiplicity of large wells, closely spaced cause great variations in well levels and a general slow decline in the piezometric surface. Well levels fall considerably during summer months when pumping rates are high, but recover during winter months. The decline of the piezometric surfaces in the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers from 1885 to 1965 is shown in Figure 29 and Figure 30, respectively. The decline in the former aquifer has reached 70 feet in Minneapolis and 90 feet in St. Paul. Corresponding declines for the Mount Simon-Hinckley aquifer are 230 feet and 170 feet, respectively. Since most of the annual recharge to the basin is still being discharged to streams and lakes the decline of the piezometric surfaces is considered to be mostly of economic significance at present. Pumping costs will increase and the continued lowering of the piezometric surface will eventually result in the cycling of water, now being naturally discharged, to beneficial uses (23).

East-Central Province. The red drift, ranging in thickness up to 300 feet, is the main source of ground water in the East-Central Province. This drift overlies mainly Precambrian igneous and metamorphic rocks and a thin wedge of Hinckley Sandstone in the eastern part of the province. Sands and sandy, somewhat clayey, materials constitute the red drift. Moderate to high water-yielding sands immediately underlie the red drift in about one-third of the province. The Hinckley Sandstone has yielded up to 400 gpm to wells in Kanabec, Isanti, and Sherburne Counties.

Glacial outwash deposits south and west of Mille Lacs Lake have produced wells yielding 500 gpm and constitute a potential source of sustained high yields for irrigation and industrial use. The same is true of the outwash deposits in the Upper St. Croix basin. The surficial deposits of the Mississippi River basin above St. Paul contain the largest quantities of available water within the province (23).

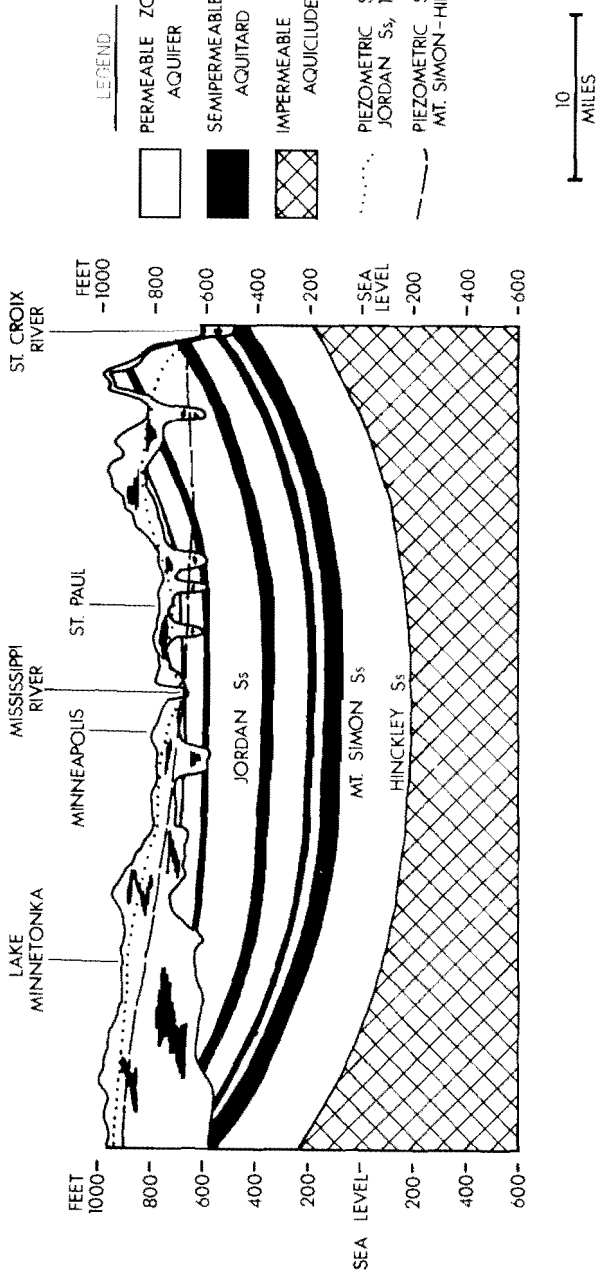


FIGURE 28. GENERALIZED GEOLOGIC AND HYDROLOGIC CROSS-SECTION OF THE TWIN CITIES ARTESIAN BASIN, MINNESOTA (23)

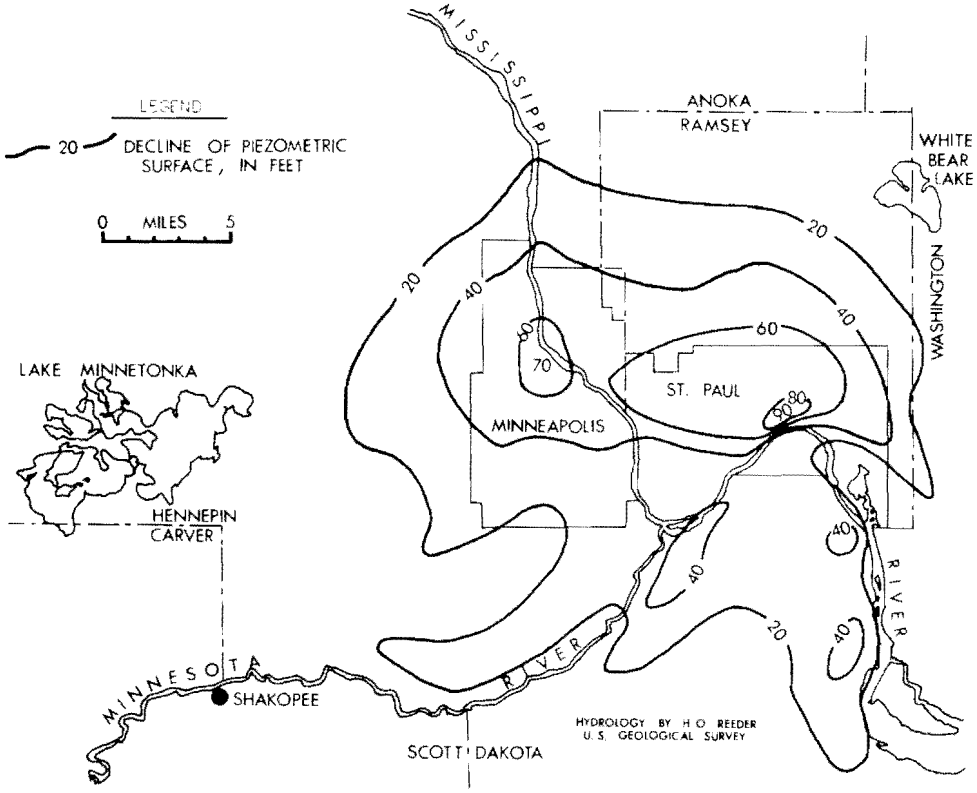


FIGURE 29. DECLINE OF THE PIEZOMETRIC SURFACE OF THE PRAIRIE DU CHIEN-JORDAN AQUIFER, TWIN CITIES ARTESIAN BASIN, MINNESOTA FROM 1885- 965 (23)

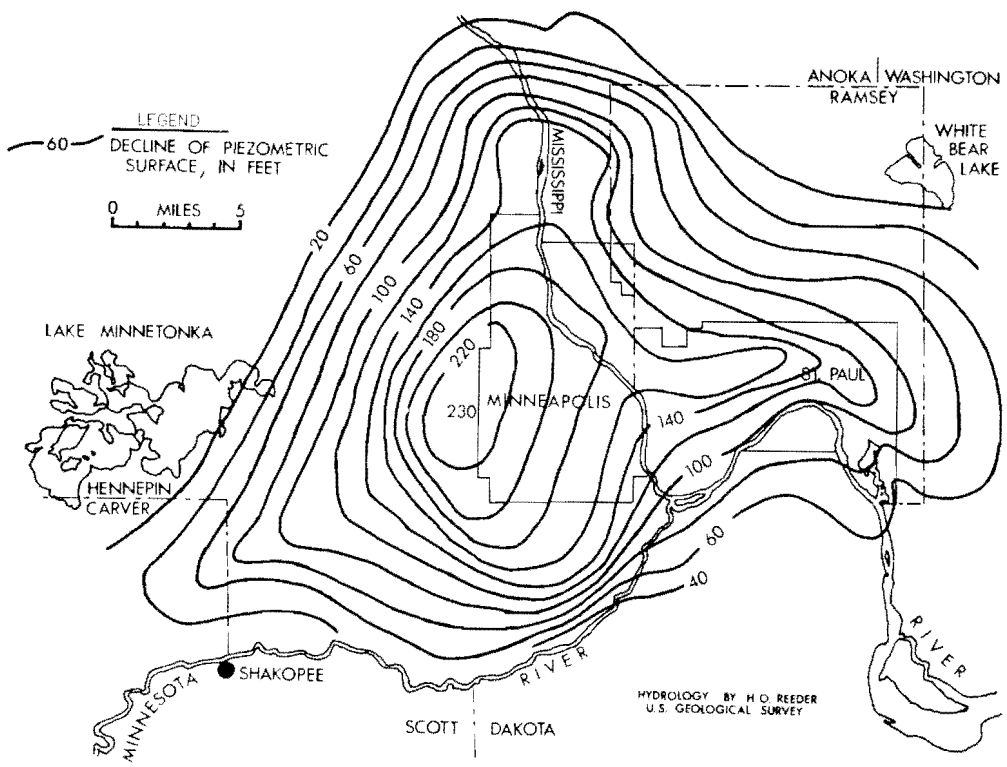


FIGURE 30. DECLINE OF THE PIEZOMETRIC SURFACE OF THE MOUNT SIMON-HINCKLEY AQUIFER, TWIN CITIES ARTESIAN BASIN, MINNESOTA FROM 1885 TO 1965 (23)

Arrowhead Province. Glacial drift provides the only reliable sources of ground water in the Arrowhead Province. The drift cover in the province is, however, thin and well yields are generally only sufficient for domestic uses.

The principal, relatively untested, aquifers are to be found in the red drift and post-glacial deposits. Small yields of water can be obtained from the 50- to 100-foot thick sand bodies found in the drift in the southwestern part of the province, from alluvial and beach deposits, and from fractured Precambrian basement rocks (23).

Western Province. Ground-water yields vary from good to poor in this province depending mostly upon the presence or absence of sand bodies in the drift in the northern part, and on thickness and position of the Cretaceous sand beds in the southern part. Glacial lake plains in the province include those of the famous Lake Agassiz occupying a 500 square mile area (Figure 31), Lake Benson just north of the Minnesota River, and Lakes Aitkin and Upham south of the Mesabi Range. Large areas of outwash sands and valley trains attaining thicknesses of 500 feet outcrop in the area between the Eastern-Central Province and the Lake Agassiz plain and south of the Mesabi Range.

The glacial drift contains many aquifers. Yields to wells in the glacial till and lake plain sediments are generally low and the water very hard and high in iron content. Where the glacial drift comes into contact with Cretaceous or Paleozoic rocks the ground water is too high in chloride content for human consumption. The shallow gravelly beach sands, and shoreline and river channel deposits are the most prolific aquifers but the water is very hard and high in dissolved solids. Buried sand and gravel bodies are second in importance with well yields averaging 100 to 200 gpm. The water is moderately hard, moderate to high in iron, low in manganese and with chloride content varying from 10 to 200 ppm (23).

Low yields of poor quality water characterize the bedrock aquifers. The Cretaceous sandstones produce hard, saline water high in iron content, while water from the Paleozoic beds is unfit for human consumption.

Sand bodies up to 100 feet thick in the Mesabi Range are the most mapped and tested aquifers in the province. These and the iron ore bodies of the Range produce moderate to high yielding wells. The water is hard to very hard, high in manganese and iron content, moderately siliceous, and low in dissolved solids.

IV. WATER USE

For the purpose of this section, water use will be considered under the following main categories: public supplies from public water utilities; rural (including domestic and livestock but not irrigation); irrigation; self-supplied industrial (including thermoelectric power generation as shown); and hydroelectric power generation.

The terms "withdrawal" and "withdrawn" will be used to describe water removed or diverted from sources such as streams, lakes, and aquifers. Water recycled within an industry is only counted once even

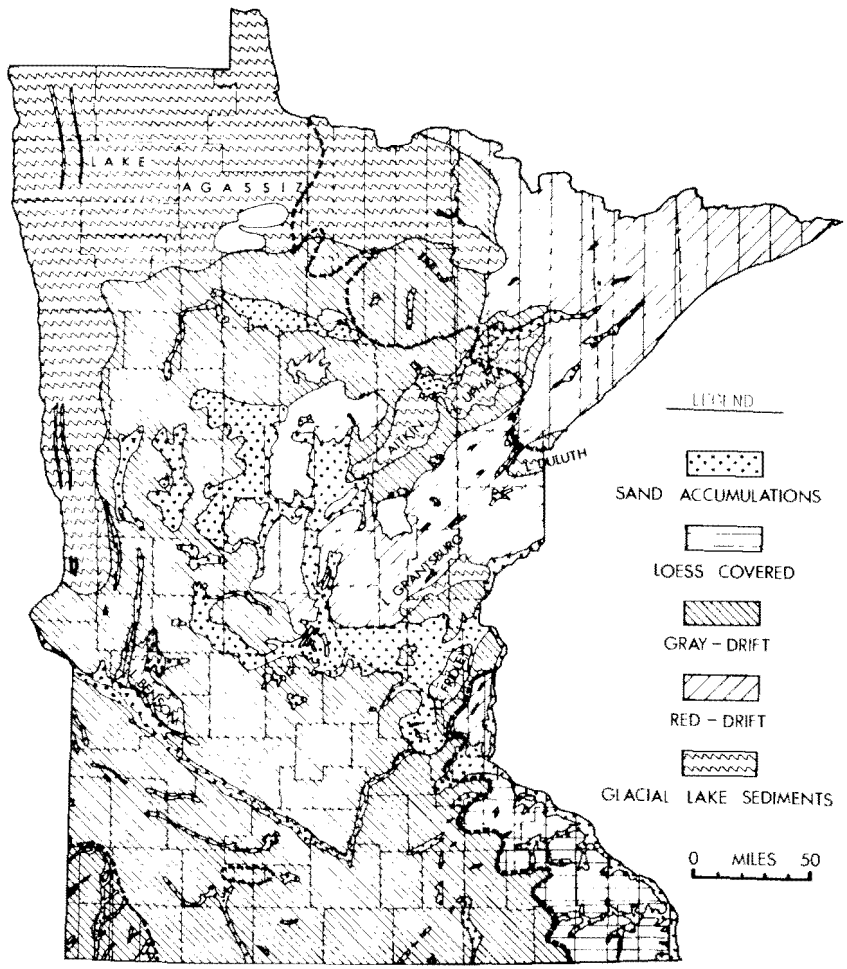


FIGURE 31. SURFICIAL GEOLOGY OF MINNESOTA (23)

though it has performed the work of an quantity two or more times its own on a once-through basis.

The terms "consumed" and "consumption" will be used with respect to water withdrawn that has been "lost" due to evapotranspiration, incorporation into products and crops, consumption by man or livestock, or other such means.

Water withdrawals in 1950 from both surface and ground-water sources in the State for all uses (exclusive of thermoelectric and hydroelectric power) averaged 424 million gallons per day (mgd). Of this total, public supplies accounted for 34 percent, irrigation 2 percent, rural 24 percent, and industrial (self-supplied) 40 percent (23). By 1965, the comparable total withdrawal use had increased more than four-fold to an average of 1,786 mgd (89). Table 10 summarizes water use both withdrawn and consumptive in 1965, including thermoelectric power use.

Table 10

Water Use in Minnesota in 1965 (89)

Category	Water (mgd)			
	Withdrawn			Consumed
	Surface Water	Ground Water	Total	
Public Supplies	120	140	260	50
Rural	10	110	120	110
Irrigation	2	4	6	6
Industrial (self-supplied)	1400	1300	2700*	110
Total	1532	1554	3086	276

* Includes 1300 mgd for thermoelectric power use.

The daily per capita supply to the estimated 2.43 million persons served by public supplies in 1965 was 107 gallons. Industrial and commercial establishments used an estimated 100 mgd or 39 percent of the 250 mgd withdrawn that year for public supplies. About 45 percent of the total withdrawals for public supplies came from ground-water sources and 19 percent of the total was estimated consumed.

An estimated 92 percent of the rural withdrawals was consumed mainly for rural domestic use and livestock watering. All of the water withdrawn for irrigating approximately 24,000 acres of land was considered consumed.

Ground-water sources supplied 1300 mgd of the total industrial withdrawals with the remaining 1400 mgd coming from surface water sources. Of the total industrial supply, thermoelectric power plants used 1300 mgd or approximately 50 percent. Most of this was used for condenser cooling. Air conditioning used an estimated 20 mgd of self-supplied industrial water, and 12 mgd of public water supplies. Industrial uses consumed very little of the water supplied, the estimated quantity being 110 mgd or about 4 percent.

Hydroelectric power plants accounted for withdrawals totaling 30,000 mgd in 1965 (not shown in Table 10). This type of power plant is expected to continue to supply a significant portion of the State's future requirements because of their ability to supply large amounts of power, on short notice, to meet peak power demands (89).

The distribution of water withdrawals throughout the State subdivided into nine areas is shown in Figure 32 for the year 1950 (23). Largest withdrawals were in the Metropolitan Area with 174 mgd or 41 percent of the total, and the Great Lakes Basin with 55 mgd or 13 percent. This is not surprising in view of the concentration of population and industry in the Metropolitan Area, the Iron Range Area, and Duluth. The distribution of irrigation withdrawals for the same year is shown in Figure 33 and also seen to be concentrated around the Metropolitan Area (23).

The Water Resources Coordinating Committee of the State Planning Agency has made projections of water use through the year 2020 (89). Table 11 is a summary of these projections by uses (excluding thermoelectric and hydroelectric) and major river basins. Total withdrawals are expected to increase from 1,159 mgd in 1960 to 3,290 mgd in 2020 or about 2.8 times. Consumption over the same period is expected to increase 1.8 times from 162 mgd to 287 mgd.

In 1960, the Mississippi and Missouri River Basins provided about 47 percent of the total water withdrawn, with about 42 percent coming from the Great Lakes Basin, and the remaining 11 percent from the Red-Rainy River Basin. These percentages are expected to change to 63, 30, and 7 respectively in the year 2020. Table 12 shows the relationship of withdrawals further subdivided over a number of smaller river basins.

The Committee expects that the Twin Cities Metropolitan Area and the Great Lakes Basin will continue to dominate the withdrawals but their joint percentage of the total will decrease from 69 in 1960 to 66 in 2020. Withdrawals in the Great Lakes Basin are expected to decrease from 42 percent to 30 percent of the total during this period but the percentage withdrawal in the Metropolitan Area should remain constant at about 32. Withdrawals in the Minnesota, Cannon-Zumbro-Root, and Upper Mississippi (below the Twin Cities) River Basins are expected to grow in relative importance to those of other basins.

The Committee recognizes that the increased water demands will be met in part by increased withdrawals but in larger part by better management. Problems in meeting the quantitative demands from current sources

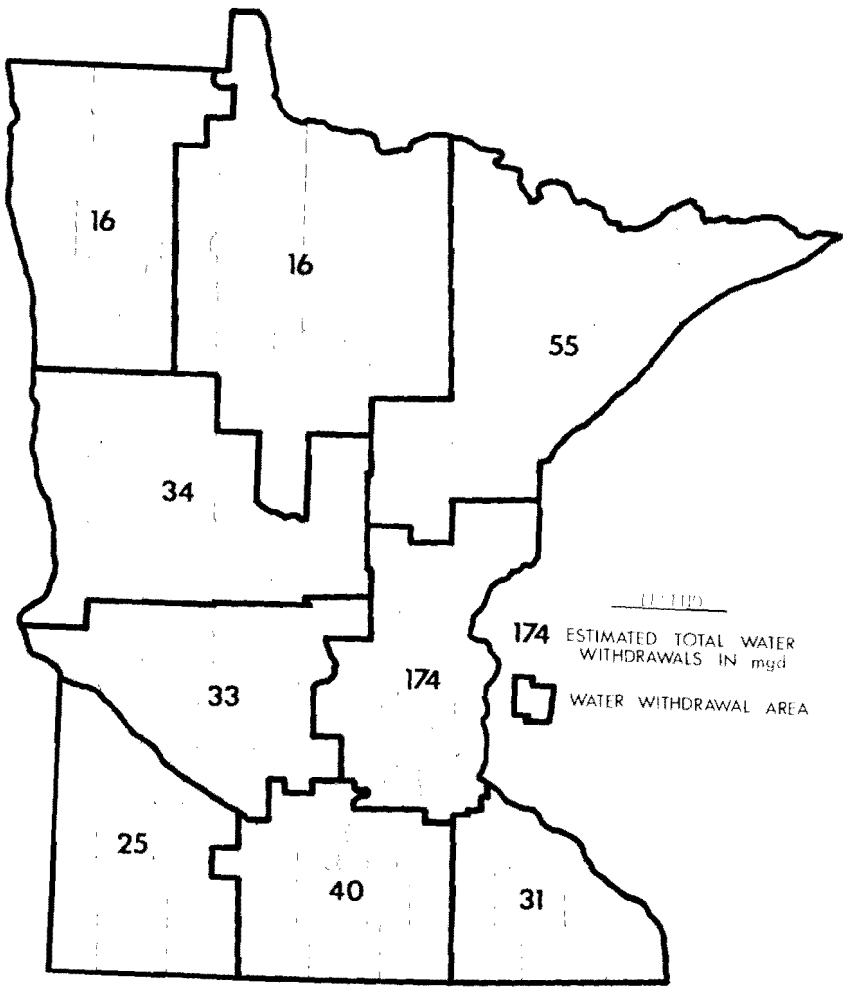


FIGURE 32. ESTIMATED WATER WITHDRAWALS IN MINNESOTA IN 1950 (23)

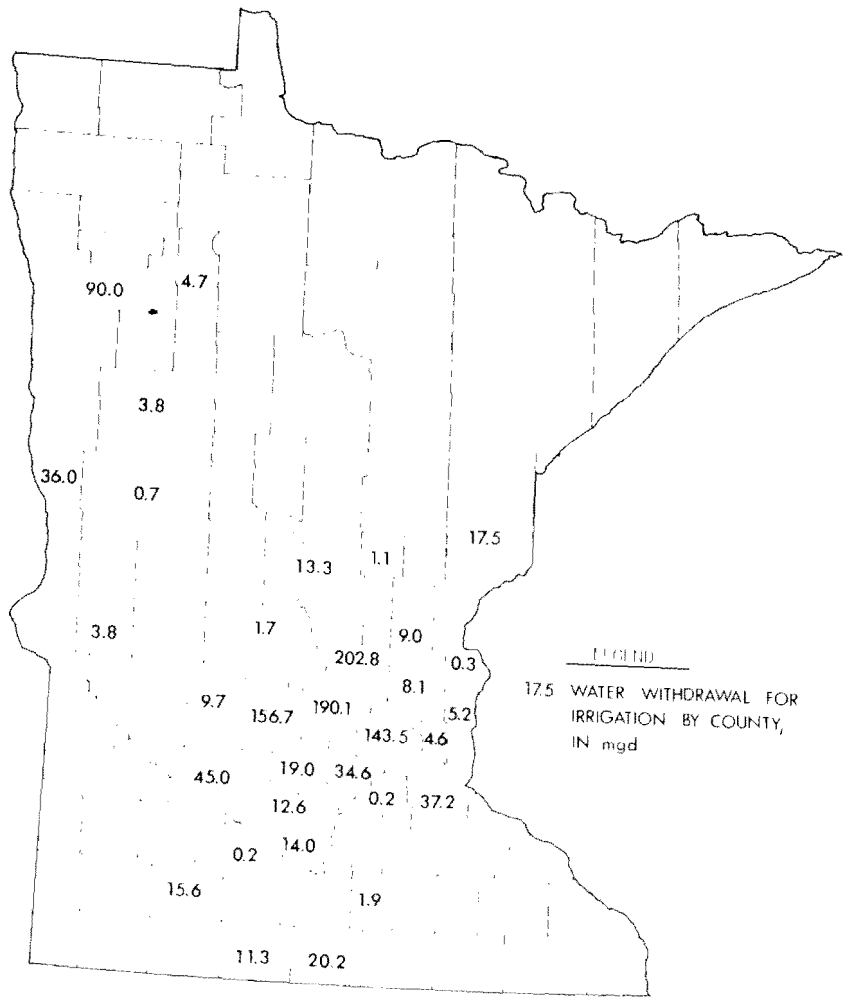


FIGURE 33. WATER WITHDRAWALS FOR IRRIGATION IN MINNESOTA IN 1950 (23)

Table 11

Summary of Projected Water Use in Minnesota
Excluding Thermoelectric and Hydroelectric Power Uses
1960 to 2020 (89)

Use	1960 Water (mgd) Withdrawn	1960 Water (mgd) Consumed	1980 Water (mgd) Withdrawn	1980 Water (mgd) Consumed	2000 Water (mgd) Withdrawn	2000 Water (mgd) Consumed	2020 Water (mgd) Withdrawn	2020 Water (mgd) Consumed
Great Lakes Basin								
Public Supplies	23	5	31	7	52	11	80	17
Rural	3	3	4	4	5	5	6	6
Irrigation	-	-	-	-	-	-	-	-
Self-supplied Industrial	457	20	760	33	800	35	914	42
Subtotal	483	28	795	44	857	51	1,000	65
Upper Mississippi and Missouri River Basins								
Public Supplies	201	12	393	41	606	53	935	70
Rural	80	73	72	66	65	60	63	58
Irrigation	6	6	7	7	13	13	18	18
Self-supplied Industrial	256	9	500	15	694	21	1,054	32
Subtotal	543	100	972	129	1,379	147	2,070	178
Red-Rainy River Basin								
Public Supplies	12	1	18	2	28	4	42	5
Rural	33	30	34	31	35	32	36	33
Irrigation	1	1	1	1	2	2	3	3
Self-supplied Industrial	87	2	101	3	118	3	139	3
Subtotal	133	34	154	37	183	41	220	44
Total	1,159	162	1,921	210	2,419	239	3,290	287

Table 12

Relative Water Withdrawals from River Basins
of Minnesota (89)

Basin	Percentage of Total Withdrawals 1960	1980	2000	2020
Upper Mississippi River Headwaters (including Twin Cities)	27	28	30	33
Great Lakes	42	41	36	30
Minnesota	6	8	8	9
Red-Rainy	11	8	8	7
Cannon, Zumbro, Root	4	6	7	9
Missouri	1	1	1	1
Upper Mississippi River Main Stem (below Twin Cities)	7	6	8	9
Rest of State (South and East)	2	2	2	2
Total	100	100	100	100

are anticipated to arise in the major areas shown in Figure 34 in the years indicated. Looking at the Twin Cities area, withdrawal demand, it is pointed out, should rise from 362 mgd in 1960 to 639 mgd in 1980; 816 mgd in 2000; and 1300 mgd in 2020. Of these demands, ground-water sources of the area, with maximum capacity 600 mgd, are expected to supply 200, 300, and 400 mgd in the years 1980, 2000, and 2020, respectively. Surface water sources must, therefore, supply 439 mgd (680 cfs) in 1980; 516 mgd (790 cfs) in 2000; and 900 mgd (1,390 cfs) in 2020. Adding the 350 cfs of flow required to accommodate the expected traffic increase through the locks at St. Anthony Falls, the total stream flows needed in the Mississippi through the Twin Cities are expected to be 1,030 cfs in 1980; 1,140 cfs in 2000; and 1,740 cfs in 2020. The 1-day-in-30-years low flow at Anoka (about 15 miles upstream of the Twin Cities) being only 650 cfs, the Committee concludes that a water supply problem would occur in the Twin Cities area around the year 1980.

It should be pointed out at this stage that inadequate water quality may increase the present restrictions on water use in the Twin Cities area and create a "water supply problem", possibly earlier than 1980 if adequate water quality management practices are not undertaken. The same

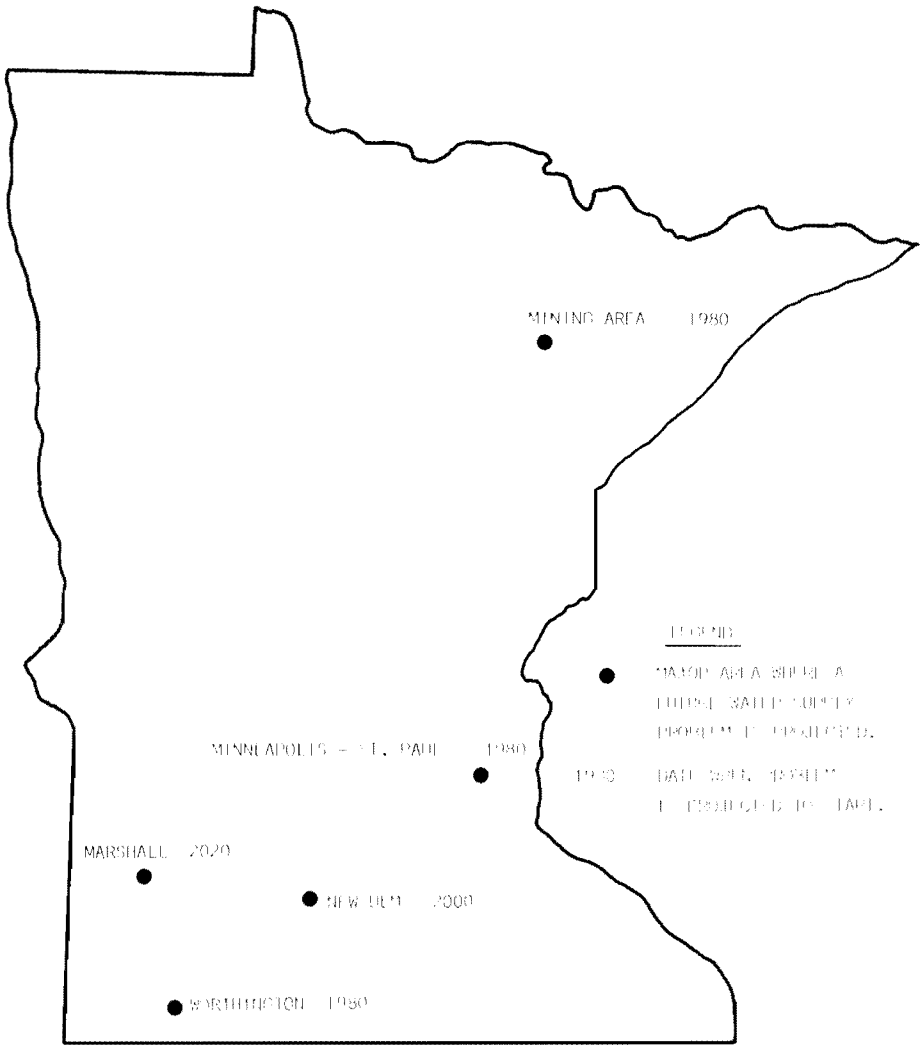


FIGURE 34. POTENTIAL MAJOR WATER SUPPLY PROBLEM AREAS OF MINNESOTA (89)

will be true for the waters of the Great Lakes, Rainy River, and Red River of the North Basins. This point will become clearer following the discussion on water quality and pollution in the next section. Water quality management must be an integral part of water resources management in the State.

V. WATER QUALITY

This section describes the natural chemical characteristics and pollution problems of the State's water resources. Reference is made to the State Planning Agency's Bulletins No. 2 (23), and No. 3 (89).

Chemical Characteristics

Lakes. The quality of lake waters in the State are generally influenced by the geology of their locations. In northeastern Minnesota where igneous and metamorphic rocks outcrop lake waters have low concentrations of readily soluble substances. Lakes of central Minnesota that are underlain with red drift contain marl deposits and their waters are poorer in nitrogen and phosphorous than those in gray drift areas but richer than those in the igneous rock region. The highest concentrations of dissolved salts such as carbonates, sulfates and chlorides are found in the lakes of the southwestern region where gray drift overlies Cretaceous rock formations. Waters in this region are also highest in nitrogen and phosphorous content.

Precipitation into, and evaporation and discharge from lakes also influence their water quality. The chemical constituents of lakes in the northeastern region of the State are continually being diluted by the relatively high precipitation, as well as being lost from the lakes with the outflow. The land-locked lakes of the southwest, by contrast, only have intermittent outflow in wet years and salts tend to accumulate. This concentration of salts is further increased by evaporation which exceeds rainfall by about 10 inches annually in the southwest. On the other hand, annual rainfall exceeds evaporation by about 10 inches in the northeast.

Generally, lakes are shallower in the direction northeast to southwest across the State. This has been attributed both to their origin and the greater eutrophication or ageing of the more fertile southern lakes. Because of the greater ratio of bottom area to volume in shallower lakes, salts diffused from the beds of such lakes also exert a greater influence on the chemical quality of lake waters.

The most common concentrations of total alkalinity, sulphate, chloride, total phosphorous, and nitrogen in lakes across the State are shown in Figure 35. The trend, earlier described, towards increased concentrations in a southwesterly direction is seen in all cases. The ranges of the same set of chemical constituents are given in Table 13.

Streams. Variations in the mean concentrations of various chemical constituents and the stream flows corresponding to high and low concentrations of hardness are shown for major rivers of the State in Table 14.

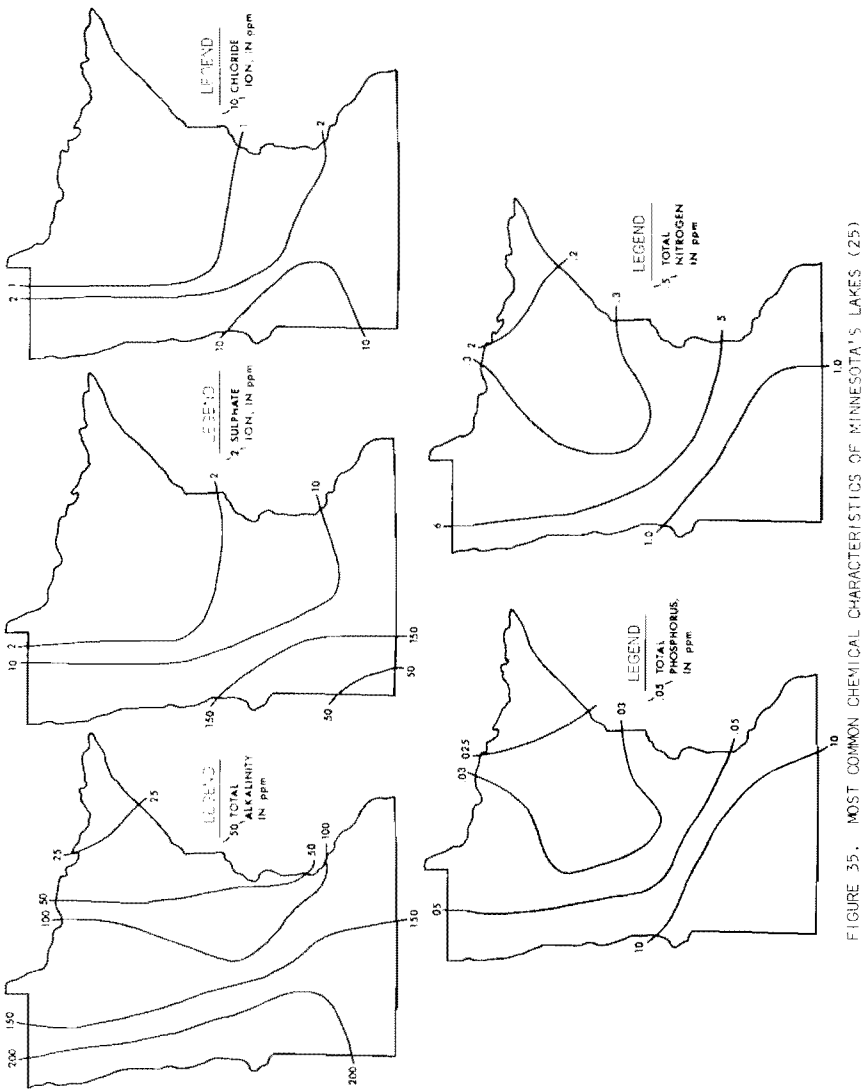


FIGURE 35. MOST COMMON CHEMICAL CHARACTERISTICS OF MINNESOTA'S LAKES (25)

Table 13

Ranges of Chemical Constituents
in Minnesota's Lakes (23)

Constituent	Concentration (ppm)	
	Minimum	Maximum
Total Alkalinity	6.3	537.5
Sulphate	0.0	1,210.0
Chloride	0.0	113.0
Total Phosphorous	0.002	1.6
Total Nitrogen	0.06	5.9

Generally the dissolved solids concentration is less than 500 ppm but exceed 1000 ppm in some streams at low flow. The highest concentrations of dissolved solids are found in western streams and the lowest in the northeastern streams. Calcium and bicarbonate are the principal dissolved constituents. Some streams, mainly in the west, show a change from magnesium bicarbonate and sulfate dominance at low flows to the corresponding calcium salts at high flows. The waters of most streams in the southern and western parts of the State are hard at nearly all discharges. Higher sulfate concentrations are also found in these streams.

Ground water. The ground waters of the surficial deposits of southern Minnesota show a decided decrease in total mineralization in an easterly direction. This is attributed to the influence of the Cretaceous formations in the west and Paleozoic ones in the east. The southeasterly part of this region contains moderately mineralized waters of mainly calcium and magnesium in equilibrium with the bicarbonate radical; low chloride, sulfate, sodium and potassium; and total solids ranging from 431 to 463 ppm. Ground waters of the southwestern part are highly mineralized; high in calcium and magnesium hardness; and with total solids varying from 868 to 1,417 ppm. The north central part exhibits characteristics that are generally intermediate between the first two.

In northeastern Minnesota the dissolved solids content of ground waters average 230 ppm with calcium, magnesium and bicarbonate being dominant; significant concentrations of sulfate are present; and iron manganese content are generally high.

The ground waters of northwestern Minnesota exhibit increased salinity in a westerly direction with the Lake Agassiz sediments (1362 ppm) and the Cretaceous beds (2,333 ppm) producing the most saline water.

Table 14

Variations in Chemical Constituents in Minnesota's Streams (23)

Station Location	Constituents (ppm)							Stream Flow (cfs) at Times of High & Low Hardness	
	SO_4	Cl	Fe	NO_3	Hardness				
					Mean	High	Low	Low	High
St. Louis River									
Aurora	22	5.2	0.52	1.7	64	100	28	73.4	898
Scanlon	21	14.2	0.62	1.5	94	187	52	1,330	7,590
Mississippi River									
Grand Rapids	7.9	1.9	0.9	0.4	142	172	88	1,220	2,010
Royalton	9.3	2.1	1.2	0.6	143	182	80	3,200	26,600
Anoka	17.0	4.1	0.6	1.5	168	192	106	3,270	59,300
Winona	29	7.5	1.5	3.2	152	181	86	12,900	206,000
Minnesota River									
Montevideo	252	13.6	0.08	3.5	461	710	238	52	4,690
Mankato	165	14.1	0.05	5.8	475	545	244	294	2,520
Carver	141	19.9	0.04	7.9	386	504	294	686	16,000
Red River									
Fargo	54	0.7	0.02	0.8	235	280	136	2,787	4,600
Grand Forks	63	2.1	0.005	0.7	248	310	126	1,517	25,300

In the Twin Cities area, ground waters from the glacial drift increase in dissolved solids content from about 250 ppm in the northeast to about 700 ppm in the southeast with a median of 250 ppm. The median value of the dissolved solids in the water of the St. Peter Sandstone, and the Shakopee and Oneota dolomites is 344 ppm. In the Jordan Sandstone, the median dissolved solids content is 275 ppm with a narrow range of 250 to about 375 ppm. The Franconia-Galesville and Mount Simon-Hinckley have median dissolved solids content of 272 ppm increasing from 200 to about 600 ppm in a southwesterly direction. The water from all aquifers is generally suitable for municipal and domestic supplies but excessive iron and manganese concentrations necessitate treatment before use in most industries (90).

Pollution

Lakes. Most of the lake pollution problems in the State stem from the discharge of treated and untreated municipal wastes, wastes from private disposal systems, industrial and agricultural wastes, and runoff from agricultural lands into them. Of particular concern is the increased eutrophication of the lakes that results from the addition of nutrients (mainly phosphorous and nitrogen) contained in waste discharges. Lakes usually move from an oligotrophic state of low fertility and production of organic matter through a eutrophic state of high fertility and productivity of organic matter, the remains of which accumulate in the lake beds eventually filling the lakes to create swamps. Eutrophication of a lake is, therefore, referred to as an ageing process resulting in eventual "death" of the lake. The addition of nutrients via waste discharges increases the natural eutrophication process. Excessive blooms of algae, weeds and aquatic growths are characteristic of lakes subject to such "man-accelerated" or "cultural" eutrophication. These excessive growths adversely affect recreational activities such as boating, water-skiing, swimming and fishing, and, by the creation of tastes and odors, the use of the water for domestic and other purposes.

The soft-water lakes of northeastern Minnesota are less fertile than those in the south and west and exhibit no severe algae and aquatic weed problems. In addition, the lakes in the northeastern parts of the State have steep shorelines that do not favor the growth of submergent or emergent weed species. The Department of Conservation's annual reports summarizing its aquatic nuisance control work identify the main problem areas. These occur where heaviest human use coincide with high lake fertility. Lakes within fifty miles of the Twin Cities area and the triangular shaped lake region outlined by lines joining the Twin Cities, Grand Rapids to the north, westward to Detroit Lakes and thence to Alexandria and Willmar in the Minnesota River valley are the most problematical. Figure 36 shows the approximate location of eighty-eight lakes that have required treatment to control blue-green algal blooms. Lakes receiving sewage effluent are indicated in Figure 37. Most of these lakes are known to have weed and algal blooms (89).

Big Stone Lake at the mouth of the Minnesota River is a very highly fertile lake that has been experiencing severe algal blooms and other aquatic growths. A study (91) undertaken by the Minnesota Pollution Control Agency in 1967, concluded that drainage of the mainly agricultural

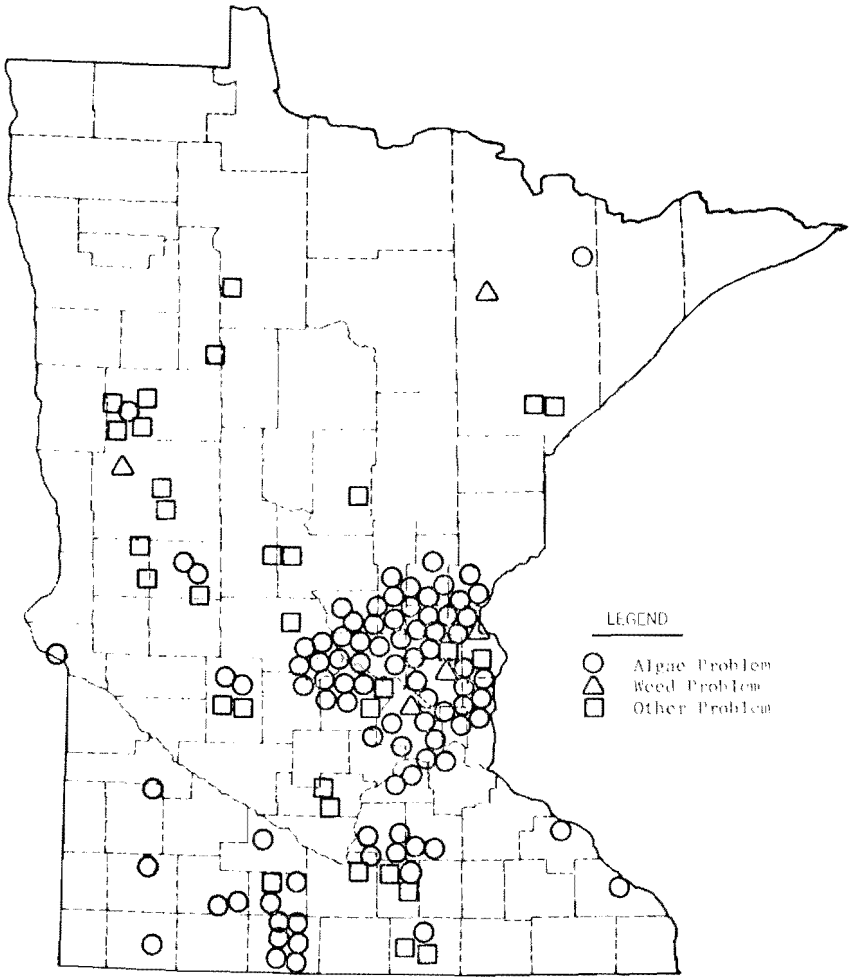


FIGURE 36. MINNESOTA'S LAKES WITH WATER QUALITY PROBLEMS (89)

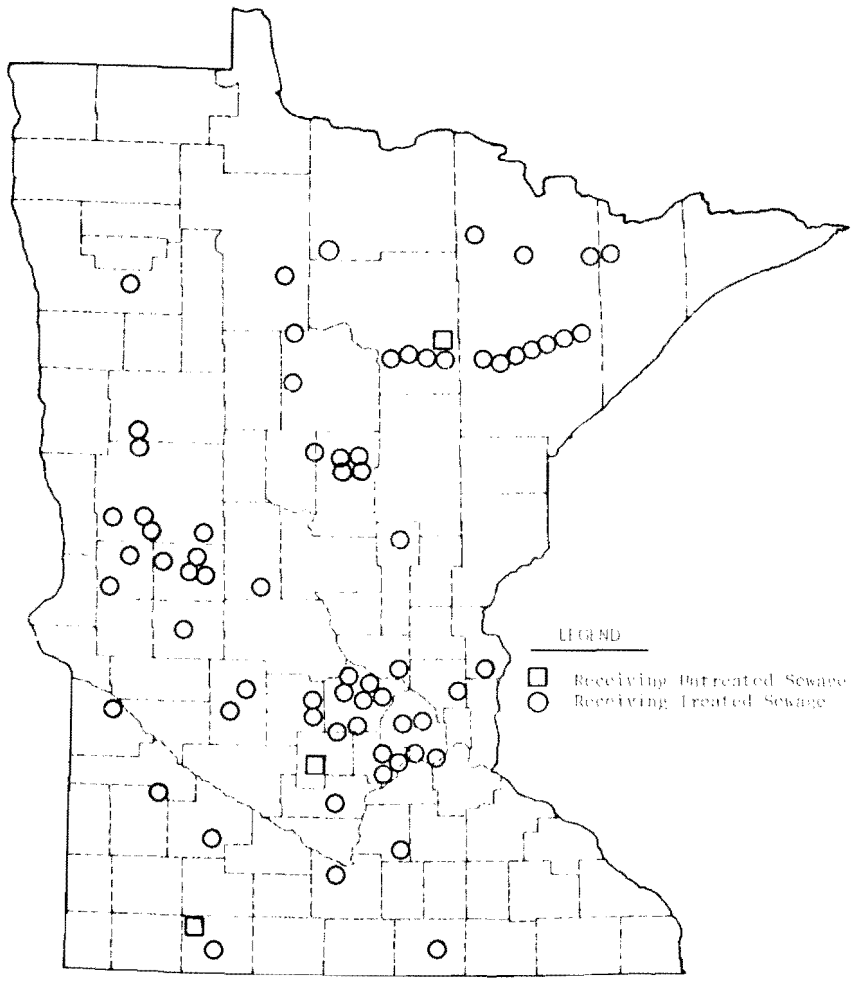


FIGURE 37. MINNESOTA'S LAKES RECEIVING SEWAGE EFFLUENT (89)

lands and solid wastes disposed from livestock feed-lots may be contributing significantly to the eutrophication of the lake. The study identified eight sites from which there was evidence of animal wastes equivalent to the oxygen demand of the raw sewage of 13,000 people reaching the lake. These sites contributed an estimated 66 pounds of phosphorous daily to the lake.

Streams. The pollution problems of the major river basins of the State have been summarized by the Water Resources Coordinating Committee of the State Planning Agency (23, pp. 387-98) and by Gibson and Walton (92) from the findings of a variety of studies. This section is based upon material from those two sources, and broadly describes the situation as it existed in 1967.

Upper Mississippi River Main Stem. Pollution had resulted in low dissolved oxygen levels, high densities of coliform bacteria and aesthetical degradation with adverse effects on several water uses at many points along the Upper Mississippi River Main Stem (23). Figures 38 and 39 indicate problem areas and the sites of municipalities and industries contributing to those problems. The criteria used in establishing problems were dissolved oxygen (DO) levels below 5 mg/l, and total coliform density exceeding 1000/100 ml during the recreation and navigation season upstream of the Minneapolis-St. Paul Sanitary District (MSSD) outfall; and DO levels less than 3 mg/l, and coliform densities greater than 5000/100 ml between the MSSD outfall and Lock and Dam No. 2.

The largest of the twenty-eight contributors of treated municipal waste were the cities of St. Cloud, Minneapolis-St. Paul, and Winona in Minnesota, and La Crosse in Wisconsin. Four paper manufacturers, three meat-packing plants and a chemical plant were the principal sources of inadequately treated or untreated industrial wastes. Six of 21 communities listed on the Minnesota side of the basin provided only primary treatment for their wastes. The MSSD completed the initial stage of its secondary treatment facilities in 1968.

Fish and wildlife propagation, recreation and aesthetics were among the uses impaired by pollution upstream of St. Cloud. Discharges from paper companies in the vicinity of St. Cloud and from the St. Cloud sewage treatment plant further impaired water quality for the above mentioned uses and in addition increased the coliform densities so high as to inhibit the use of the water for the irrigation of crops not ordinarily cooked. Greatest use of the Mississippi River for irrigation in Minnesota was normally made in the reach between St. Cloud and Anoka. Between Anoka and St. Anthony Falls the river was suitable for all uses but whole-body water contact activities and the same applied between St. Anthony Falls and the MSSD outfall except after rainfalls when combined sewer overflows further degraded the bacteriological quality. The major waste discharges from the MSSD and South St. Paul sewage treatment plants and sixteen other smaller ones made the segment of the river between the MSSD outfalls and Lock and Dam No. 2 suitable for use only as cooling water. The increased flow and dilution provided by the entry of the St. Croix River was offset by discharges from Hastings, Minnesota and Prescott, Wisconsin and despite the oxygenation that occurred in the passage of the

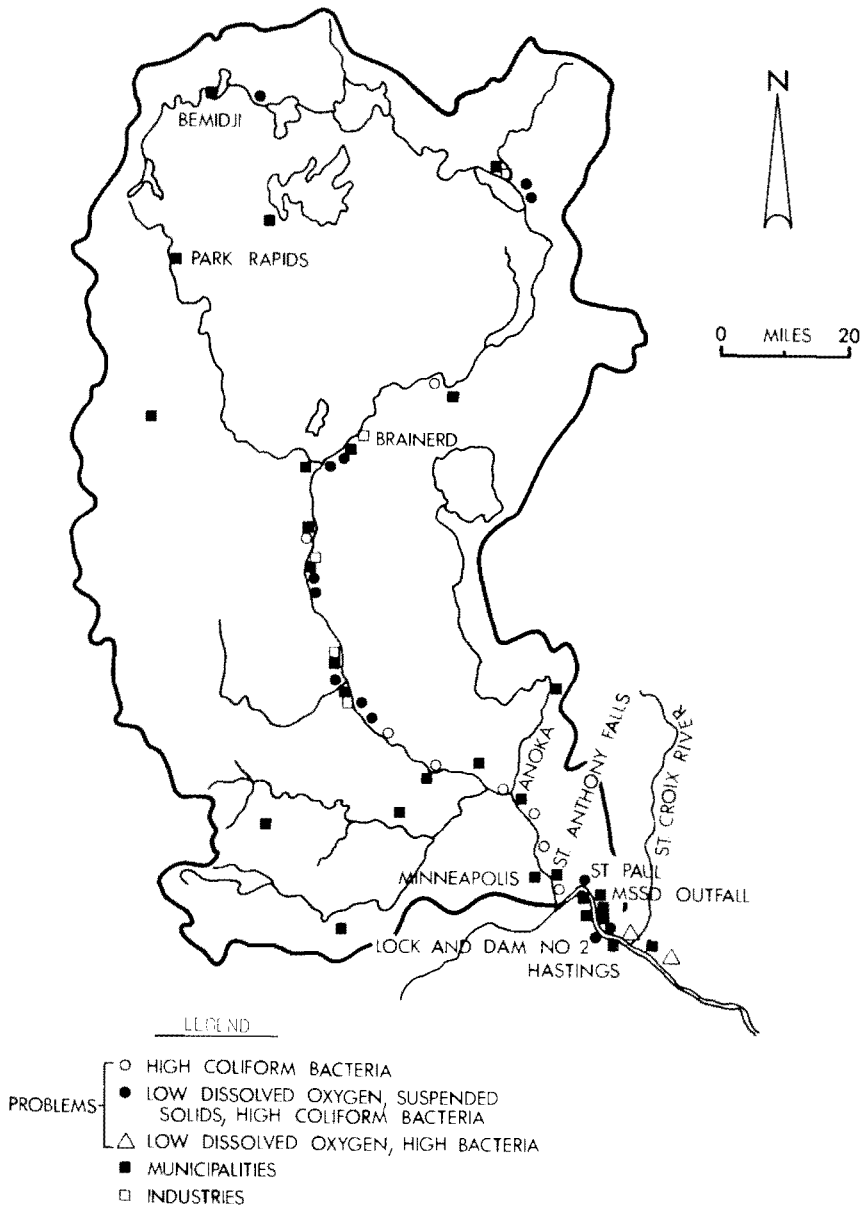


FIGURE 38. WATER POLLUTION PROBLEM AREAS OF THE UPPER MISSISSIPPI RIVER MAIN STEM ABOVE THE ST. CROIX RIVER (23)

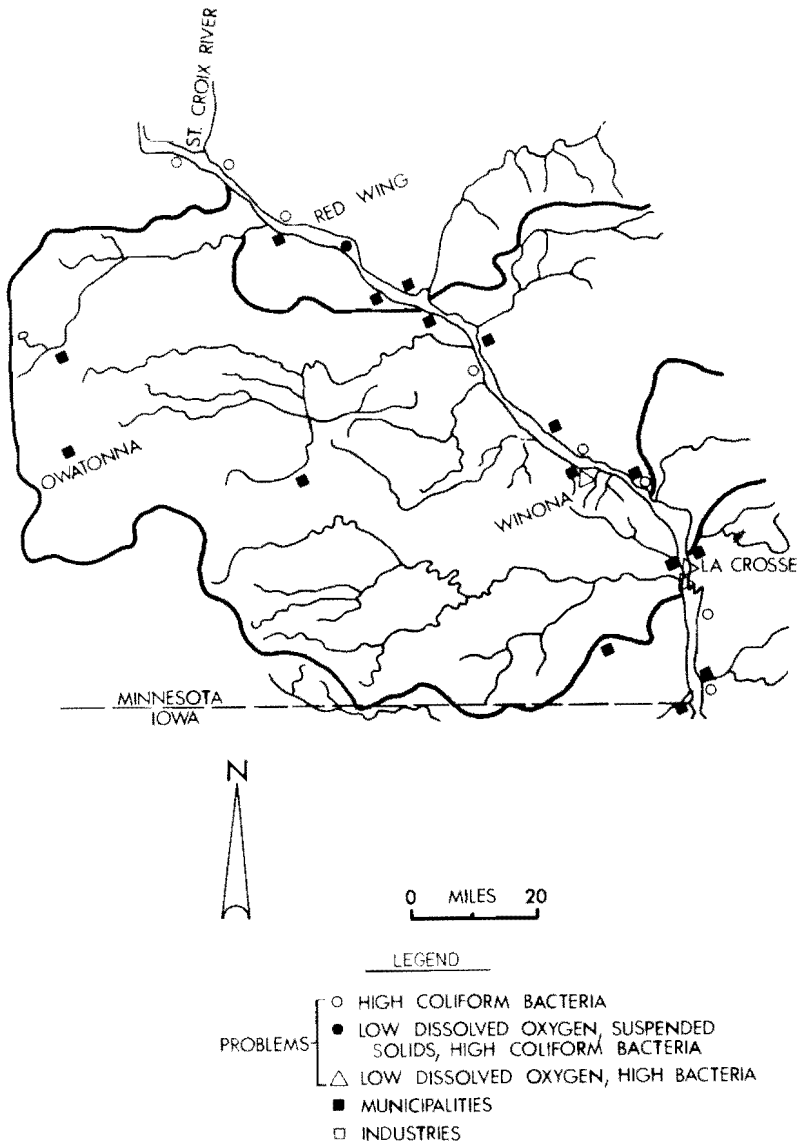


FIGURE 39. WATER POLLUTION PROBLEM AREAS OF THE UPPER MISSISSIPPI RIVER MAIN STEM BELOW THE ST. CROIX RIVER (23)

water over Lock and Dam No. 2, the desirable lower DO limit of 5 mg/l was not maintained. The water quality was sufficiently improved at the entry of Lake Pepin to permit limited body contact activities and stock and wildlife watering (92).

Minnesota River Basin. Excessive algal growths and suspended sediment, low levels of dissolved oxygen and high bacterial densities were among the pollution problems (Figure 40) of the Minnesota River Basin. The algal and other aquatic growth problems of Big Stone Lake have already been described. High levels of suspended sediment were to be found throughout the entire river. Low dissolved oxygen and high bacterial densities occurred below Ortonville, Granite Falls, Redwood Falls, New Ulm, and industrial sites at Chaska and below Vernon Center on the Blue Earth River. Recreation, fish and wildlife propagation, municipal and industrial water supply and aesthetics were among the water uses adversely affected at various points along the river (23).

The St. Croix Basin. The St. Croix River was essentially undefiled by man for a distance of about 110 miles from its source to St. Croix Falls, Wisconsin. Municipalities and industries discharged treated and some untreated wastes to the river below St. Croix Falls (Figure 41). Occasional high coliform densities resulted in the immediate vicinity of the outfalls but otherwise the water quality was suitable for all water uses (23).

St. Louis River Basin, St. Louis Bay and Superior Bay. The major pollution problems of the St. Louis River occurred in the section of the river between Cloquet and St. Louis Bay. The main contributors to these problems were the city of Cloquet and its industries (mainly pulp, paper making and chemical), the city of Duluth and its industries (steel and pulp board), and the city of Superior, Wisconsin and its industrial (oil refining, gravel washing and creosote). The problems of low dissolved oxygen levels and high coliform densities have been showing no improvement over the years since 1928. Recreational uses have been curtailed, public beaches closed, fish kills have occurred and coliform densities have been so high in all sections below Cloquet as to be indicative of a possible public health hazard (23).

Red River Basin. Pollution problems on the Red River of the North included the development of septic conditions, severe oxygen depletion, high total dissolved solids concentrations, high bacterial densities and various other nuisance conditions. The problem areas are indicated in Figure 42. Coliform densities as high as 160,000/100 ml has been recorded below Fairmont near the source of the river, and 2.8 million/100 ml below Fargo and Moorhead in the main channel. The Sheyenne River contributed high coliform densities presumably from the drainage of cattle feeder pens, holder pens and other cattle yard drainage in the area of Southwest Fargo. At times, only pollution tolerant organisms had been found for several miles below Fargo-Moorhead and septic conditions had occurred below Grand Forks. Excessive algal blooms had also occurred below Fargo-Moorhead during open water periods, creating taste and odor problems and reduced filter runs in water treatment plants. Improved waste treatment facilities under construction, and planned for most of the cities on the main stem of the river should effect some improvement (23).

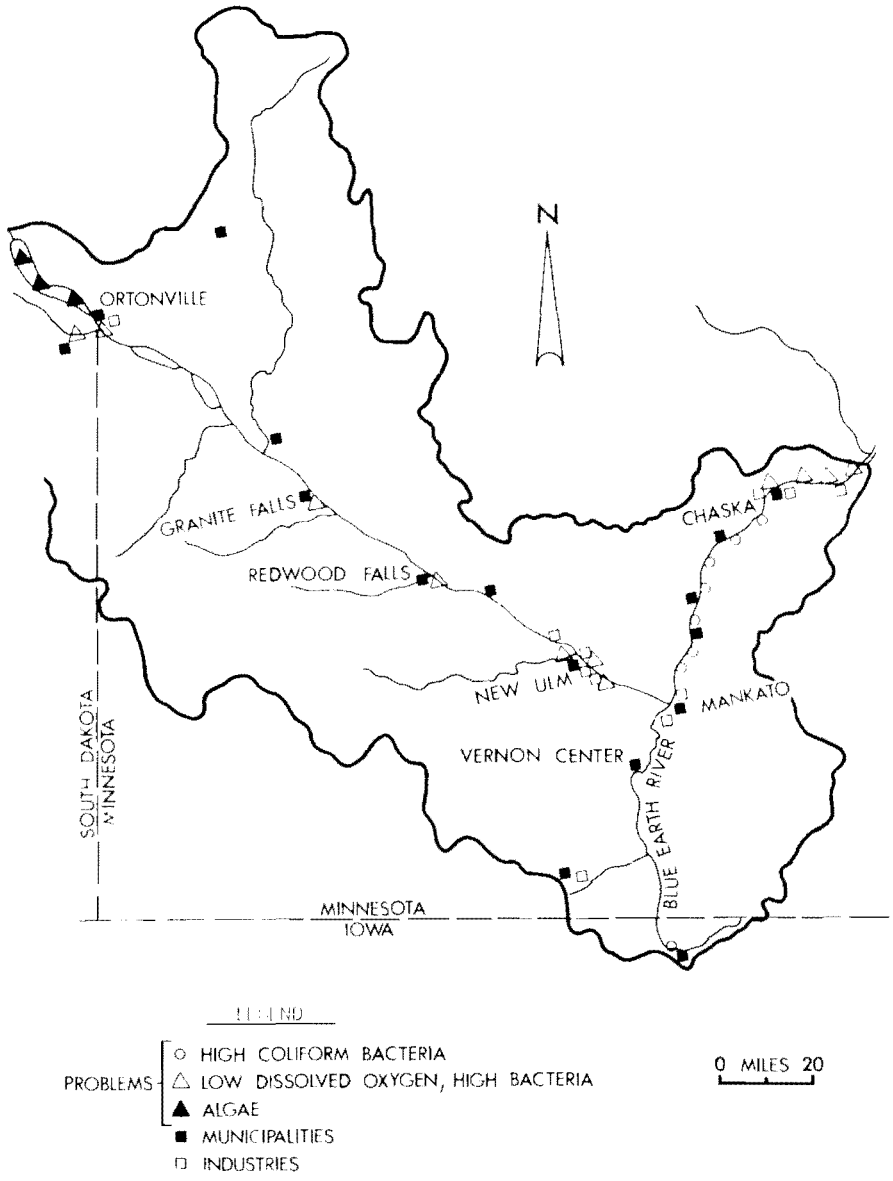


FIGURE 40. WATER POLLUTION PROBLEM AREAS OF THE MINNESOTA RIVER BASIN (23)

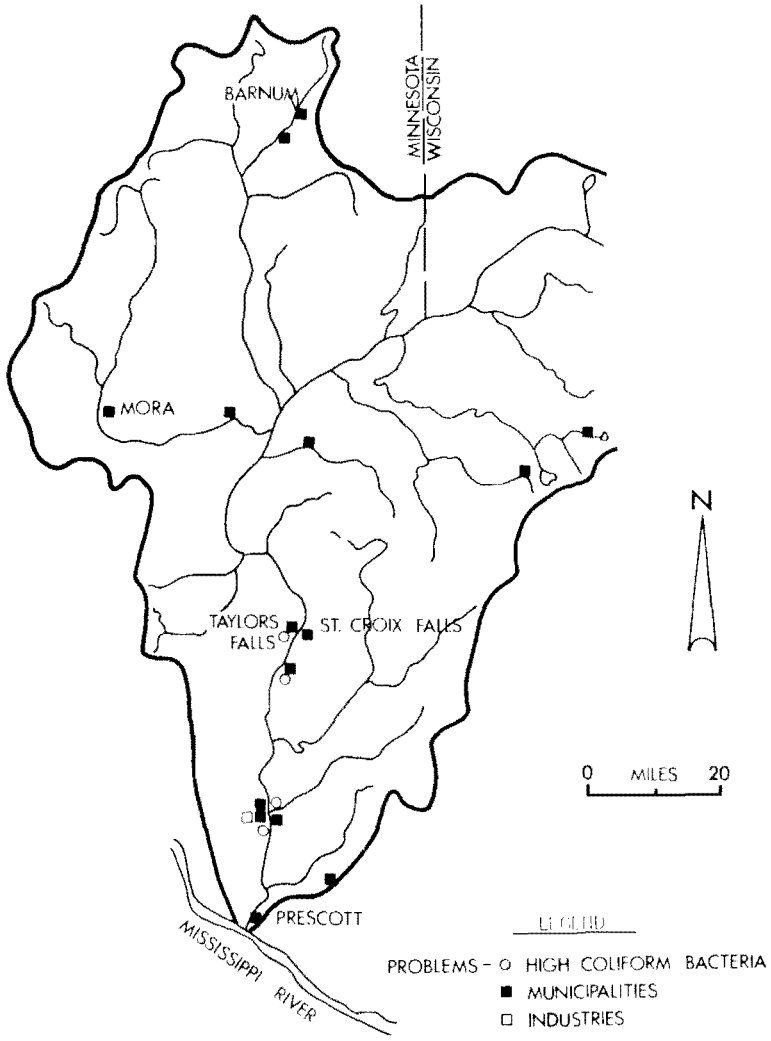


FIGURE 41. WATER POLLUTION PROBLEM AREAS OF THE ST. CROIX RIVER BASIN (23)

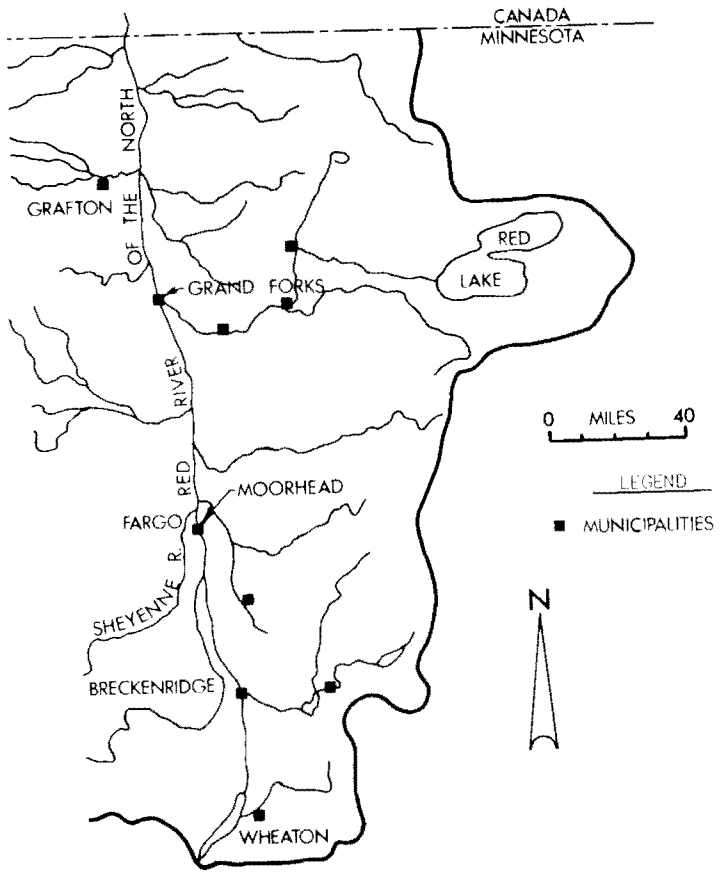


FIGURE 42. WATER POLLUTION PROBLEM AREAS OF THE RED RIVER BASIN (23)

Rainy River Basin and Lake of the Woods. The Rainy River has in the past exhibited high coliform densities and dissolved oxygen depletion between International Falls and Baudette with a return to satisfactory quality in Lake of the Woods (Figure 43). The paper companies at Fort Frances and International Falls had been the major contributors to this problem with the cities of Fort Frances and Baudette in significant supporting roles. High coliform densities, exceeding 6,000/100 ml for 60 miles below International Falls had made it necessary to provide auxiliary pre-treatment measures before use as drinking water. Unsightly and odorous deposits from the pulp and paper mills had detracted from the aesthetic value of the stream. Wood fibres and associated waste discharges had also resulted in drastic fish population reductions over the past 25 years. Improvements have been noted recently with the construction of a primary treatment plant at Fort Frances, Ontario, a secondary treatment plant at International Falls, and the installation of equipment by the paper companies to screen out fibre and wood solids from their wastes (23).

Ground water. There has been evidence in the past of sewage contamination of the relatively shallow glacial drift aquifers in the southern half of the State and particularly in the southwestern area. The problem was first recognized in the late 1940's when methemoglobinemia, a disease of infants characterized by cyanosis resulting from a diminished oxygen supply in the blood, was linked to high concentrations of nitrates in water used in preparing food for babies. Generally, the problem involved wells dug or drilled near septic tanks, cesspools, privies and animal waste disposal sites. Nitrate nitrogen concentrations in all wells linked to the disease were well in excess of the 10 ppm requirement of the U. S. Public Health Service Drinking Water Standards, exceeding 100 ppm in the wells of southwestern Minnesota. Fourteen deaths were recorded from among 139 cases in the study period 1947 to 1950. It is worth noting that none of the wells complied with the Department of Health's regulations pertaining to construction and location from sources of contamination (93).

Wells in Brooklyn Park and Richfield, suburbs of the Twin Cities, also exhibited high nitrate concentrations and alkyl benzene sulfonate (ABS) during 1960 and 1961, indicating sewage contamination from septic tanks and other such household waste disposal systems (90).

Special problems. Two "special problems" of current interest are worth discussing here: (a) the disposal of taconite tailings by the Reserve Mining Company, E. W. Davis Works into Lake Superior near Beaver Bay; and (b) pollution from the proposed nuclear power plants to be constructed by the Northern States Power Company (NSP) at points along the Mississippi.

(a) Disposal of taconite tailings into Lake Superior. Reserve Mining Company, E. W. Davis Works is the only one of 27 taconite processing plants in the Minnesota section of the Lake Superior basin and of 36 in the entire basin that is permitted to discharge taconite tailings into the lake. Fourteen of these plants employ a closed system, settling their waste waters in lagoons and then recirculating the effluent (94).

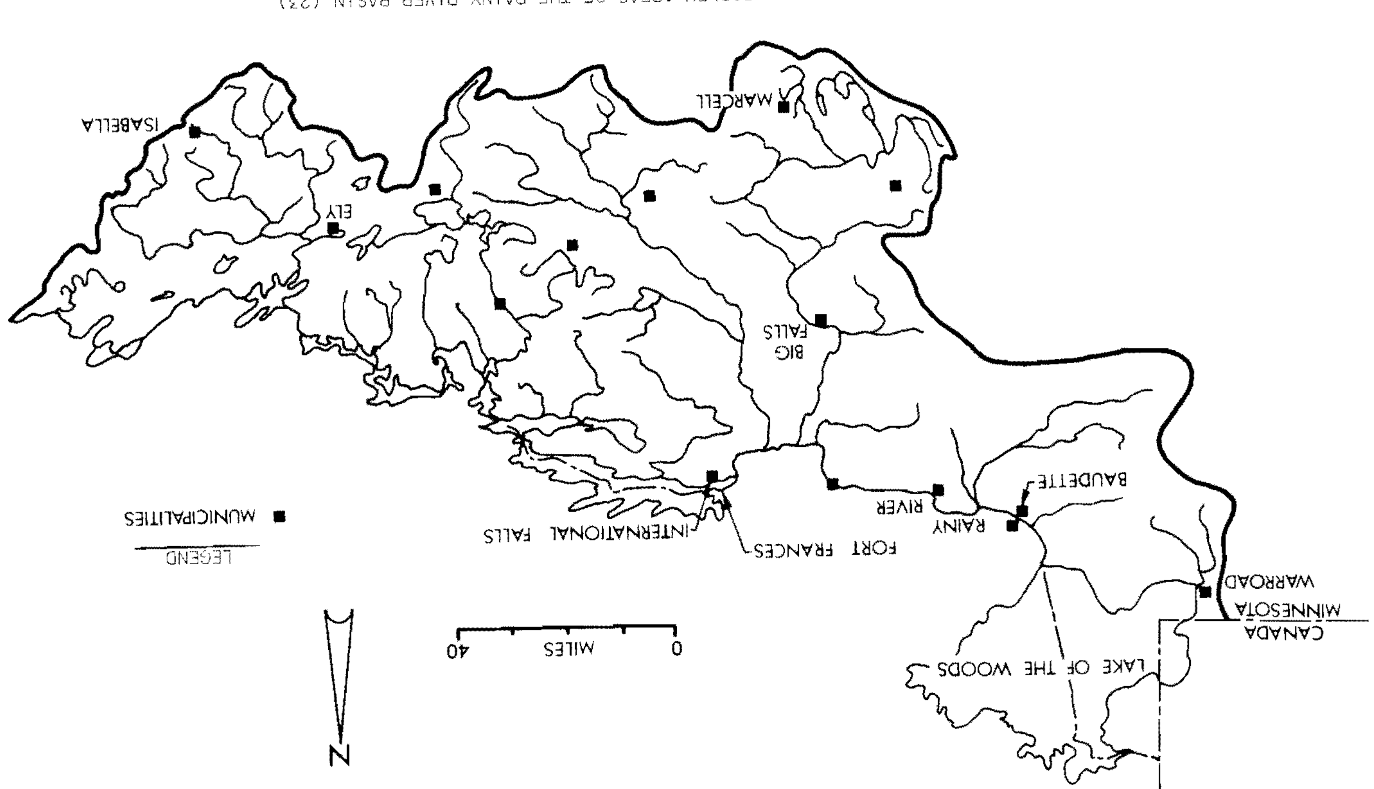


FIGURE 43. WATER POLLUTION PROBLEM AREAS OF THE RAINY RIVER BASIN (23)

The Company applied to the State Water Pollution Control Commission on January 28, 1947 and after nine public hearings was issued a permit on December 22, 1947. Evidence produced at these hearings included reports of studies on the physical and chemical characteristics of taconite tailings by the State Department of Conservation, University of Minnesota Mines Experiment Station and Reserve Mining Company, and the Wisconsin Water Pollution Control Committee; and hydraulic model studies by a private consultant and the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. The Chairman of the hearings reported "Findings of Fact" that stated that the depth of the lake and character of its bed are such as to accept the settled tailings without materially interfering with navigation or other public uses; that the major fraction of the tailings will settle within a short distance of the outfall forming a delta while density currents will finally take the more persistent minute material down to bottom; that the grayish milky appearance caused by the very fine particles will normally extend not more than a mile from the discharge, and the turbidity will be so slight as not to be materially harmful to fish life.

The permit allowed the withdrawal of approximately 130,000 gpm of water from, and its return to, the Lake with tailings. It required no "material clouding or discoloration" of the water outside a 3 mile square zone in the Lake around the discharge point, nor any "material adverse effects on fish life or public water supplies or in any other material unlawful pollution of the waters of the Lake or in any material interference with navigation or in any public nuisance outside of the said zone." It further required the company to get a navigation permit from the appropriate federal agency (U. S. Army Corps of Engineers), and is subject to revision, or revocation only in case of violation of its terms.

The permit is indeed very vague, describing only in the broad general terms mentioned in Chapter I, what "material discoloration" the quality degradation that would result in revocation. The later amendments in 1956 and 1960 did nothing but extend the rates to 260,000 gpm and 502,000 gpm, respectively, and required the Company to make more extensive turbidity measurements, bottom sampling to account for tailings and accumulations in the delta, and studies to determine the causes and effects of "green water" and slime on fish nets occurring in the Lake. The terms of the permit are so vague as to be virtually impossible to enforce. As pointed out in Chapter I, the recognition of the need to specify water quality in a quantitative manner is relatively recent. The terms of the permit should be rewritten in specific terms taking into consideration the findings of recent studies undertaken in connection with enforcement hearings (94).

The "green water" phenomenon in the vicinity of the discharge, and "net slime" are the problems that prompted the recent interest in possible pollution by the tailings. The Federal Water Pollution Control Administration (94), using more advanced techniques than previously available, found that tailings are in the "green water" in which the turbidity is two to three times higher than in clear water elsewhere in the Lake; that bottom deposits of taconite are destroying fish food organisms; some fish fry are being killed by high concentrations of taconite wastes; and that taconite tailings were reaching the municipal water supplies of

cities as far south as Duluth, Minnesota. Evidence produced at the hearing in September, 1969, showed that the tailings have crossed interstate boundaries into Wisconsin.

Despite the studies undertaken prior to the issuance of the permit in 1947, evidence given at recent hearings indicate that the major consideration influencing the issuing of the permit was the economic benefit of the industry to the area, and that the likely effects of the discharge on the lake received only incidental consideration as a result. The clause in the permit requiring the Company to start substantial construction work within five years and have at least one unit of its plant operating within ten years lends credence to this argument. So does the uniqueness of the permit when compared with the rest of the industry. Whatever was the case, water quality considerations should now be given greater weight and made to play their most important role in the management of this valuable lake resource in the light of the recent findings.

(b) Nuclear Power Industry. Special mention is being made here to the nuclear power industry only because it is almost completely new to the State except for the rather small (22 megawatts), essentially experimental Federally owned plant at Elk River which has been out of operation since 1966. Because it is new, it brings with it new problems about which there has been considerable public interest recently.

The Northern States Power Company (NSP) is presently completing a 545 megawatts plant at Monticello, about thirty-four miles upstream of the intakes of the Minneapolis and St. Paul water treatment plants on the Mississippi River. This plant is due to go into operation on May 1, 1970, while two others, each of capacity about 550 megawatts, are planned for Prairie Island, just north of Red Wing on the Mississippi and about forty miles downstream of the Twin Cities, with completion dates of May 1, 1972, and May 1, 1974.

The operation of these plants will add a new dimension to pollution problems and water quality management in the State, viz that due to radioactive waste disposal. Great public controversies have arisen over the levels of radioactive waste discharges to be permitted to water and the environment generally (even whether any at all should be permitted), and as to whether the State has the legal right to set more stringent standards than the U. S. Atomic Energy Commission. The latter issue is now before the courts. Also receiving more attention than has been customary is the thermal pollution because of the once-through water circulation cooling system planned for these plants and the great quantities of heat likely to be added to the river. The Company plans to operate cooling towers to alleviate the problem.

The debate has been very lively as to the limits of radioactive waste discharges that can practically and economically be achieved by nuclear plants; what effects, immediate and long-term, these discharges may have on the environment and the population; whether nuclear power is indeed the answer to the State's rapidly growing power needs which are expected to double every ten to fifteen years; whether the water cooling systems should be of the closed circuit type; whether a mixing zone for the hot water discharges should be permitted before stream standards are

enforced; and what adverse effects, if any, the thermal discharges would have on the aquatic environment. These are some of the problem areas that require consideration and decision-making by water management agencies in the State.

VI. WATER RESOURCES MANAGEMENT

This section examines the legal framework governing the management of Minnesota's water resources prior to discussing the institutional and administrative arrangements for management of the resources. The extent of governmental involvement and policies of governmental agencies are examined in relation to the concept of integrated water management developed in Chapter 2, and comparisons are made with the institutional criteria proposed in Chapter 3.

Legal Framework

As in all other states of the Union, the United States Government exercises, within the authority of its Constitution, the ultimate control over navigable waters, and powers to regulate commerce among States and with foreign nations, see Corker (24) and Haik et al. (71). From these powers have stemmed Federal legislation relating to navigation, flood control, irrigation, and power.

The Federal Government has also in recent years passed legislation with far-reaching consequences on water resources management. These include the Water Resources Research Act of 1964, Public Law 88-379, fostering research; the Water Resources Planning Act of 1965, Public Law 89-80, encouraging comprehensive basin-wide planning by States; the Water Quality Act of 1965, Public Law 89-234, requiring States to develop and enforce approved water quality standards for interstate waters with failure to do so resulting in Federal Government intervention; and the Wild and Scenic Rivers Act of 1968, Public Law 90-542, preserving stretches of many rivers, including the St. Croix in Minnesota, for aesthetic enjoyment and other recreational activities.

The State of Minnesota under Article II, Section 2 of its Constitution claims concurrent jurisdiction in all waters forming common boundaries with other States and proclaims such waters and their tributaries to be common highways forever free to all citizens of the United States, without tax, duty, import or toll, Walton et al. (95).

Minnesota's water resources have been broadly classified into three categories (25, p. 352):

(a) *Natural surface watercourses* which "must have some substantial permanency and continuity and must be part of a well-defined stream or body of water."

(b) *Diffused surface waters* "consisting of waters from rains, springs or melting snow which lie or flow on the surface of the earth, but which do not form part of a well-defined body of water or natural watercourse."

(c) *Groundwaters* which "filter through the ground and collect in underground cavities, forming springs, or what are commonly known as wells."

There are further legal subidivsions which distinguish between natural watercourses, lakes or ponds and artificial watercourses; and between underground waters in definite streams, underground percolating waters and artesian waters (21).

Some of the definitions are rather inaccurate, such as the one for groundwaters referring to waters collecting in cavities, forming "... what are commonly known as wells." Surely wells are the man-made shafts extended to the "collected water" and through which the water is extracted, but certainly not formed by the collected water.

Haik et al. (21) also discuss the fact that the classification is unrealistic in view of the hydrologic interrelationships between the categories and the likelihood of problems not being confined to any single category but affecting all sections of a basin including both surface and groundwaters. They justifiably see a major problem in the common view that diffused surface waters can be diverted and used without liability and are not subject to the acquiring of rights.

These weaknesses in this aspect of State laws require the revision of these laws to bring them in line with current scientific knowledge.

In the area of water rights of land owners, the Minnesota courts have adopted a "reasonable use" modification of the riparian doctrine by which a riparian owner's right to use water is not lost by failure to exercise that right. Some restrictions are placed with respect to priorities given to particular uses, with domestic water supply enjoying supremacy over all other uses (23).

The common law-reasonable use concept has in effect been transferred by the State legislature to the Commissioner of Conservation, who now exercises authority in determining what constitutes a reasonable use before issuing a permit for such use. Property rights can now only be exercised upon receipt of such a permit. All waters capable of substantial beneficial public use have been deemed to be public waters by the Legislature and, with few exceptions, subject to the permit procedure (23).

Institutional and Administrative Arrangements

The institutional and administrative arrangements for water resources management in Minnesota are rather complex, so much so that Haik et al. (21) have ventured to say that few, if any, governmental officials and citizens clearly understand the entire system. The system is characterized by a multiplicity of agencies - Federal, State, interstate, local and private - with fragmented, duplicative and unorganized responsibilities and lacking in clear lines of authority and areas of jurisdiction.

No two lists of agencies involved and concerned with water resources management in the State are in agreement. There are at least thirty major Federal, State and interstate governmental units contributing to

the management of Minnesota's water resources and more than fifty others, both governmental and private, with some degree of concern and involvement (23; 95). The authority, functions, and policies of those agencies with the most important roles are discussed in this section with only passing reference being made to some others.

State agencies. The State agencies considered of greatest importance and relevance to this study are the Department of Conservation, the Pollution Control Agency, the Department of Health, the State Soil and Water Conservation Commission, the Water Resources Board, and the State Planning Agency. Other State agencies with varying degrees of concern and involvement are the Department of Agriculture, Department of Economic Development, Department of Highways, Iron Range Resources and Rehabilitation Commission, State Geographic Board, University of Minnesota (Water Resources Research Center, and Geological Survey Department), and Land Exchange Commission (Figure 44).

Department of Conservation. The Department of Conservation was established by the Minnesota Legislature in 1931 under the administration of a five-man Commission and a Commissioner elected by them. The Commission was abolished in 1937 and its authority vested in a Commissioner appointed by the Governor with the advice and consent of the Minnesota Senate (95; 96).

This Department is charged with conserving and promoting the wise use and management of the natural resources of the State - lands, forests, game and fish, waters, soils, minerals, and State parks. It consists of four divisions, viz: Waters, Soils and Minerals; Lands and Forestry; Game and Fish; Parks and Recreation. In addition there is a Section of Enforcement and Field Service. The Commissioner appoints Directors for each division. There are six service bureaus attached to the Commissioner's Office: the Bureau of Engineering with responsibility for land surveys, designing and supervising the construction of dams, bridges, roads, buildings, fish ponds, channel improvements, and other projects of the several divisions; the Bureau of Information; the Bureau of Boat and Water Safety which licenses boats directly and with the help of county auditors, and coordinates and enforces water safety laws through county sheriffs; the Bureau of Planning; and the Bureau of Business Management and Legal Affairs.

The Division of Waters, Soils and Minerals has general administrative jurisdiction over all public waters, surface and underground. It controls water use, work in lake and stream beds, construction of dams, bridges and crossings by the issuance of permits; coordinates and makes hydrologic surveys; cooperates with the U. S. Geological Survey in collecting basic data on surface and ground waters and water quality; makes reports and recommendations to State and Federal agencies on proposed projects for lake level control, and local and regional water supply and water management; appears for the State in water matters; and operates and maintains State-owned dams when and as required. The Division is also responsible for the administration and development of State-owned mineral lands and mineral rights (23).

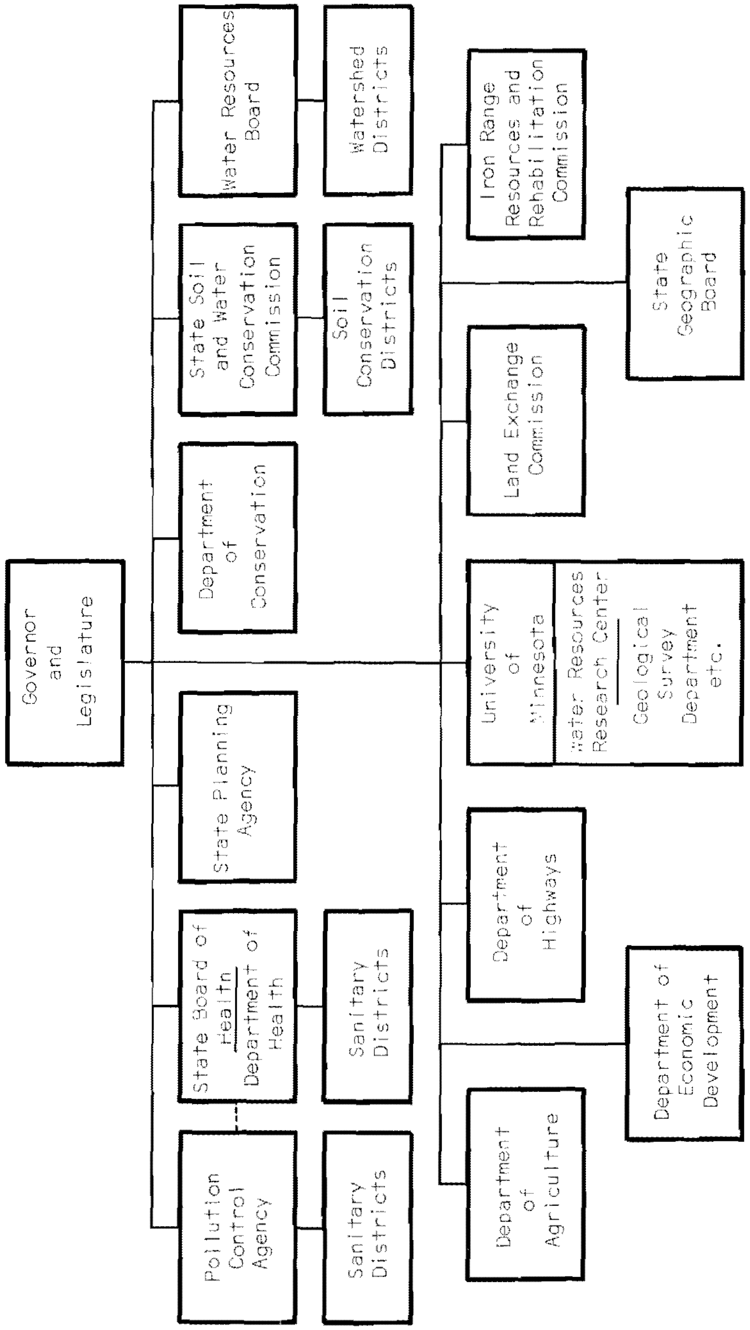


FIGURE 44. STATE AGENCIES CONCERNED WITH WATER AND RELATED RESOURCES MANAGEMENT IN MINNESOTA

The Commissioner's powers under the Flood Plain Management Act of 1969, Minnesota Statutes Chapter 590, and for the regulation of shoreland use and development under Chapter 777 also of 1969, are being administered by this Division. Model ordinances are being developed to serve as minimum requirements to be met in local government ordinances.

The Division of Lands and Forestry is mainly occupied in the management of State parks, forests, and trust fund lands outside of State forests. It has cooperated with the U. S. Forestry Service and other State and local agencies in the management of State and private lands, and forests for watershed protection including the reduction of erosion and sediment damage from floods.

The Division of Game and Fish has responsibility mainly for the management of the State's wildlife resources to ensure adequate supplies of fish and game.

The Division of State Parks and Recreation administers all State parks, maintaining facilities and historical features.

In terms of Craine's governmental techniques, the Department of Conservation engages in a limited water resource intelligence program. Limited particularly because much valuable data on water withdrawals, for example, obtained from the administration of the permit system remain unprocessed. Inadequate financing and staff shortages have been limiting this and other programs.

Like most other State agencies, this Department has been engaged in very little that can be termed long-range planning. Since the establishment of the State Planning Agency in 1967, the Department has been represented on the Water Resources Coordinating Committee which is engaged in the preparation of a comprehensive state-wide water and related land resources plan. The Department developed a preliminary outdoor recreation plan in 1965 (86), later finalized in 1968. A forestry management plan incorporating water-oriented recreation is under preparation (23).

Water use regulation by the permit system is a major activity of the Department. Appropriation of water for all uses are thus controlled. No charges are made for withdrawals.

The Department is authorized to construct and operate dikes, dams and other structures to improve navigation, domestic water supply, to protect and preserve fish and other wildlife, to protect shorelines of public waters and promote public health. It has not been doing much of this recently save for the operation of State-owned dams built in the 1930's. Emphasis of the Department is now in investigations, studies, and reports dealing with water supply. Inadequate financing has been reported as a major factor in the absence of a construction program. The Department engages in no regional distribution programs.

Despite the Department's charge by the legislature for the conservation and administration of the State's water resources, it is hardly involved in water quality management except in an advisory capacity.

Prior to 1967, the Commissioner was represented on the Water Pollution Control Commission but is not a member of the organization's successor, the Minnesota Pollution Control Agency ("MPCA"). The Department reviewed the water quality standards prepared by the MPCA prior to public hearings of them.

The Department is financed mainly by revenue from its various licensing and fee-paying activities, particularly Game and Fish, Lands and Minerals, Forestry and State Parks, and from legislative appropriations including Federal aid. Of a total expenditure of approximately $15.2 million in fiscal year 1967, less than $327,000 were spent on the State's water resources with Game and Fish (approximately $5.7 million) and Forestry (approximately $5.3 million) accounting for most of the expenditure (97). This low expenditure on water explains the repeated references at interviews with the staff to inadequate programs and staffing.

In summary, the Department of Conservation operates at Stage 6 of Graine's governmental involvement chart, using only a limited range of alternatives.

Minnesota Pollution Control Agency. This agency (MPCA) was created by the legislature in 1967 as the successor to the Water Pollution Control Commission. It consists of nine members appointed by the Governor with the advice and consent of the Senate. Terms of appointment are for staggered periods of four years. The only qualifications specified by law for members is that they be "broadly representative of the skills and experience necessary to effectuate the Policy" for which the Agency is established; that officers or employees of the State or Federal government be excluded; and that no more than two members be officials or employees of municipalities or other governmental subdivisions at any time. Present membership includes an attorney, knowledgeable in municipal government; the president of a soft-water service company; a university professor of geography and urban affairs with experience on various governmental committees; a lung and respiratory disease specialist; the vice president of a paper company; a retired banker and conservationist; an electrical engineer with considerable interest in conservation; a farmer; and a housewife. A director with executive status and powers to employ necessary staff is appointed by the Governor at whose pleasure he serves.

The Agency has State-wide jurisdiction with respect to the control of water pollution, air pollution, and solid waste disposal. Its powers and duties relevant to water pollution control are:

(a) The administration and enforcement of all laws relating to the pollution of the State's waters.

(b) The investigation and gathering of necessary data.

(c) The classification of the State's waters.

(d) The setting and revision of water quality standards.

(e) The issuance and revision of reasonable orders for the control of waste disposal in waters.

The Agency can assume the powers of defaulting municipalities and execute or have executed, on behalf and at the expense of such municipalities, works required by the Agency's lawful orders. However, it is not presently equipped, financially and otherwise, to use this authority and has never used it.

(f) Required plan inspection and approval of waste disposal systems and inspection during construction.

(g) The issuance, revision or denial of permits for waste disposal in waters.

(h) The conduct of investigations and holding of public hearings as deemed advisable and necessary for the discharge of its duties.

The MPCA has established both stream standards and effluent standards for interstate and intrastate waters and exercises its plan review and permit authorities. It is in the process of developing standards for the control of agricultural wastes from cattle feedlots. The MPCA operates a water quality sampling program on lakes and streams (98), duplicating to some extent work being done by the Department of Conservation and the U. S. Geological Survey. The State Department of Health undertakes the MPCA's water quality laboratory work by mutual agreement.

The Agency is developing a solid waste management program which recognizes the role such a program can play in abating water pollution (99); and has under study the relationship between land use management and pollution control, though it now has no authority to undertake land-use management and no explicit lines of communication with the mostly local governmental units that have the authority (100). Shoreland management regulations developed by the Department of Conservation under Chapter 777 of the Minnesota Statutes must, however, be approved by the Director of the MPCA and the State Board of Health.

The 1961 State Legislature created the *Water Pollution Control Advisory Committee* consisting of two members from each congressional district, all to be appointed by the Governor. The Committee was intended to advise the old Water Pollution Control Commission (now the MPCA) in the performance of its powers, and also to serve as a liaison with communities and industries throughout the State. However, it seldom functioned and now seems to be defunct (21).

The 1961 Legislature also authorized the creation of *Sanitary Districts* upon application to the Agency by a group of two or more adjacent areas not within the limits of a single municipality for the purpose of providing efficient waste disposal where there is a need that cannot be met by existing agencies. Such Districts are empowered to construct and maintain waste disposal and pollution control facilities and procure water supplies necessary for these purposes. Despite conditions favoring the establishment of such Districts in many areas of the State none have been created under the Act (95).

In summary, the MPCA is entirely concerned with pollution control as distinct from the broader area of water quality management. It is limited to the use of standards (both effluent and stream), plan review and a permit system for the control of waste discharges. It is not authorized to use effluent charges if such are deemed feasible and necessary. Consultants have recommended to the Agency the evaluation of the use of such charges and other water-use related fees as a continuing source of revenue (101). The Agency is entirely a regulatory one with no construction and operation activities. While it may use its plan review, permit and standard setting authority to effectuate the use by industry of waste reducing measures outlined in Chapter 2, it has no direct means for adopting the measures there described for increasing or making better use of stream assimilative capacity. Its range of alternatives are limited. Inadequate staffing and funds further limit its program (101).

Department of Health. The Department of Health operates under the supervision and control of a nine-member State Board of Health. The members are appointed by the Governor for a staggered three year term and must be "learned in sanitary science." The State Health Officer who is also the Board's secretary is elected by the Board and serves at its pleasure.

The Board, as the guardian of public health, was originally authorized by law to control, by means of licenses and permits, sewage disposal, the pollution of streams and other waters, the distribution of drinking or domestic water by private persons, and the general sanitation of tourist camps, summer hotels and resorts.

By an *Interdepartmental Agreement* (102), as required by the Statutues establishing the Minnesota Pollution Control Agency in 1967, the Department of Health now shares the statutory responsibility in health aspects of water and air pollution control with the MPCA. This agreement states the general principles on which its terms are based and then establishes requirements with respect to consultation between the Agency (MPCA) and the Department (of Health), health studies, disease outbreaks, services to the Agency, and staff transfers and reassignments.

The basic principle of the Agreement is that the Agency has responsibility for developing and enforcing standards of air and water quality and investigating land use as it affects air and water quality, while the Department's responsibilities relate to the public health aspects of pollution of the environment. The Department's responsibilities are listed as including (102, p. 2):

> determination of the health significance of water, air and land pollution; investigation of water and air-borne diseases and means for their control; provision of consultation to Agency on the public health aspects of water, air and land pollution, advising on the public health questions involved in the disposal, control or treatment of sewage, industrial wastes, other wastes or air contaminants; and the preservation of waters used for domestic water supply from pollution which may endanger the public health, and certain functions relating to the disposal of sewage at licensed trailer coach parks.

The Department is required to consult with, and advise the Agency on: (a) the health aspects of criteria for standards used to control air and water quality, and solid waste disposal; (b) specific health problems related to pollution control activities; and (c) permit applications and plan review. Provision is also made for the exchange of health-related water, air and land quality data, and of research results on a regular basis.

To facilitate its consulting role, the Department is required to undertake a variety of studies on the health aspects of pollution. These are to include: (a) epidemiological, microbiological, radiological and toxicological research and investigations into the health significance of water and air-borne contaminants of the environment; (b) epidemiological surveillance of the incidence of water and air-borne disease; (c) studies of the relationships of water, air and land characteristics and quality to the production and control of disease vectors; and (d) development of techniques for identifying, measuring and studying the behavior of water and air-borne contaminants (such as viruses, bacteria, radioactive materials, organic chemicals and trace elements) which cause or influence disease.

It is also the Department's responsibility to investigate disease outbreaks and advise the Agency when it appears that pollution may be associated with the causes of such outbreaks.

The Department is required to provide the Agency with laboratory services of all types; technical services and supporting activities necessary for the control of residential waste disposal and other minor sources of environmental pollution; and a variety of administrative services. With respect to operations normally licensed by the Department, the Agreement states that (102, p. 4):

> Health shall be primarily responsible for the examination of plans, the issuance of permits, and for the operation of disposal works which activities are carried out as an integral part of operations licensed by Health, bathing beach surveys and related investigations, and protection of domestic water supplies. Agency will do any necessary routine field monitoring or sampling Health may require in connection with Agency's activities in evaluating radioactive waste, pesticides and other health problems relating to pollution or waste disposal, and will furnish assistance and equipment upon request if special field sampling is needed.

The Agreement seems to provide an excellent basis for the fullest influence of public health factors and considerations in the administration of pollution control by an agency other than a health agency.

State Soil and Water Conservation Commission. This Commission was established by the Legislature in 1937 in recognition of the State's responsibility to provide for the conservation of its soil resources through planned and regulated land use practices in the interest of the public welfare, health and, safety (96). The Commission is comprised of nine members, five of whom are bona fide farmers appointed to five year terms

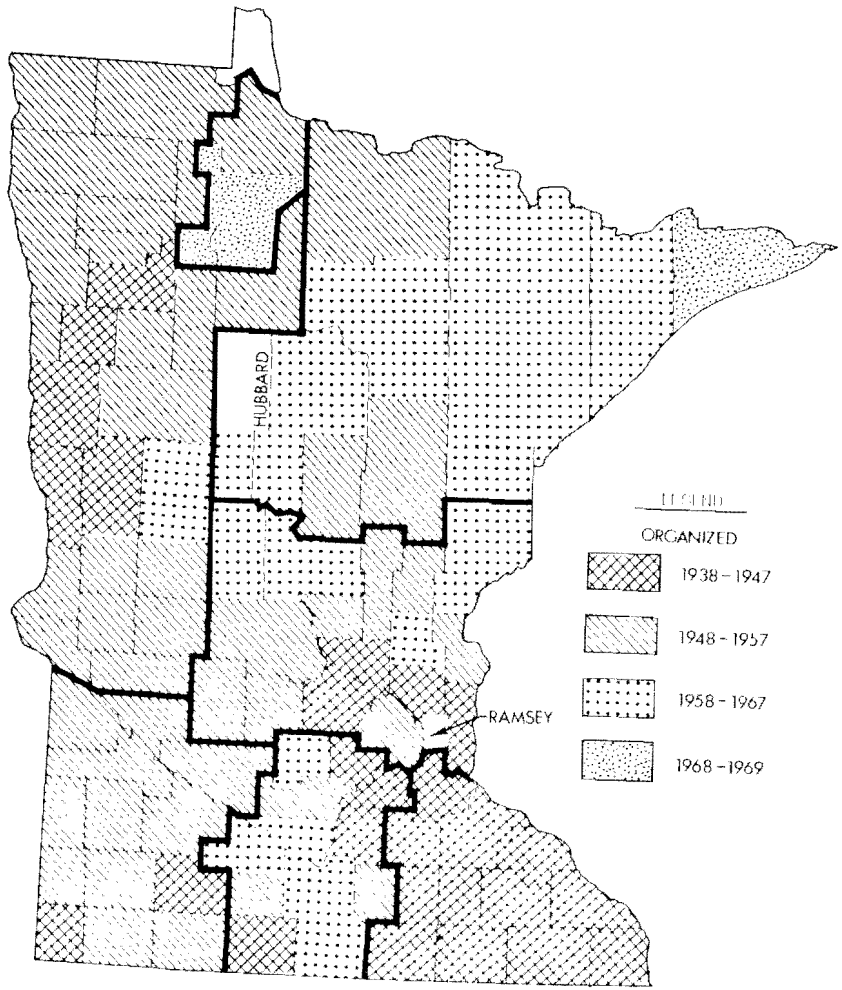
by the Governor from nominees of the State Association of Soil Conservation District Supervisors, and the following four ex-officio members: the Director of the Agricultural Extension Service of the University of Minnesota, the Dean of the Institute of Agriculture of the University of Minnesota, the Commissioner of Conservation, and the Commissioner of Agriculture. The State Conservationist of the United States Soil Conservation Service serves as advisory member.

The authorized powers and duties of the Commission are: to promote and organize Soil Conservation Districts where needed in the State; to administer funds appropriated for use by these Districts; to coordinate and assist Districts in the execution of their programs; to secure the cooperation and assistance of the Federal and State governments and agencies in the work of the Districts; to disseminate information concerning the activities of the Districts; and to subdivide and consolidate Districts as it deems necessary.

The Commission also processes applications for funding of small watershed projects under Public Law 566--reviewing plans, making recommendations to the Governor for his approval, and establishing priorities for planning purposes. This is so despite the fact that the Water Resources Board (to be described later) has the responsibility for establishing Watershed Districts, reviewing and approving their programs, and supervising their administration. According to the Commission's Executive Secretary, the legislature did not wish to give the Commission control over the implementation of projects for which it has plan review responsibilities, hence the passing of the Watersheds Act in 1955 for the creation of Watershed Districts to implement small watershed programs under the supervisory administration of the Water Resources Board. As will be shown when discussing the Water Resources Board, this action has been very unsuccessful and has merely added to the duplication and confusion that characterizes water resources management in the State.

Soil Conservation Districts are established after a prescribed form of petition from twenty-five land occupiers to the Commission, hearings to establish need, and a referendum. Each District upon formation is directed by a five-member board of supervisors who are elected by the land occupiers of the District. The Districts are generally organized within the geographical boundaries of counties. To date, ninety-one Districts have been established, covering all of the State but Hubbard and Ramsey Counties with the last two Districts being organized after 1967 (see Figure 45). A petition is being processed for Hubbard County but none has been made from land occupiers of Ramsey County. Note that the use of the "petition system" has, in this case, taken more than thirty-three years to organize less than the entire State. This subject will be returned to later in this chapter.

Originally agriculturally oriented, the functions of the Soil Conservation Districts were broadened in scope in 1965 to include in addition to the control and prevention of soil erosion such other areas as the control of flooding, stream and lake siltation, and water pollution; and the conservation and use of the land, water and related resources of the Districts. This has created conflicts with other State agencies already having jurisdiction in these various areas. References have been made by



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officers of both the Soil and Water Conservation Commission and the Department of Conservation of conflicts arising from the activities of the Districts in recreational and other areas. Article 40.13 of the Minnesota Statutes requires State agencies with jurisdiction over, or administrative charge of, State-owned lands within the boundaries of Soil Conservation Districts to cooperate with the supervisors of those Districts and give them free access to enter and perform work on such publicly owned lands. Nowhere is there mention in the laws of the Districts being required to cooperate with jurisdictional agencies to ensure compatibility of programs. It seems that cooperation has been demanded from the wrong sources. Jurisdiction has become questionable.

The Executive Secretary of the Commission is a member of the Water Resources Coordinating Committee of the State Planning Agency and thus provides input into Statewide plans now being developed.

The Districts are not developmental type agencies. Works are executed by individual land owners, Watershed Districts under Public Law 566, State subdivisions, particularly County Boards, and District Courts.

Sources of financing for the Districts are State and Federal appropriations, County funds, and revenue raised mainly from tree planting and other such activities. Funding is inadequate for service needs (103). Expenditures in 1967-68 were $57,259 by the Commission, and $310,759 by the eighty-nine Districts (103). The record shows that in twenty-eight years 57,607 or 41.4 percent of all farmers in the State requested technical assistance, with 35,004 or 25.2 percent of all farmers receiving such assistance for soil and water conservation (103). This cannot be considered an effective program in view of the small proportion of farmers served.

Water Resources Board. This Board was created under Minnesota Statutes 105.71 by the 1955 Legislature. Its members must be conversant with the water problems and conditions of the State's watersheds and not be governmental officers or employees of any type, State, Federal, or local. Appointed by the Governor with the advice and consent of the Senate, the members may number from three to five with the first three appointed for staggered six year terms and the fourth and fifth for three and five year terms, respectively. The Board designates its Chairman, subject to possible annual changes and can employ staff as required by its functions.

The Board was created primarily in recognition of the "seeming contradictions" in the numerous Statutes for the administration of water policy and to provide "a forum where the conflicting aspects of public interest involved can be presented and by consideration of the whole body of water law the controlling policy can be determined and apparent inconsistencies resolved" (Minnesota Statutes 105.72).

The Board's jurisdiction can only be invoked by petition by heads of State and Federal agencies, and organizations and groups of persons deemed representative by the Board; or by court referrals. The Board decides if petitions are worth its consideration and, if so, after hearings, makes written policy recommendations to the agency concerned.

The Board is authorized to subpoena and cross-examine witnesses and require the production of records. Only four petitions have been processed by the Board, none since 1961, and its decision in one case has been completely ignored by the head of the State agency to whom the recommendation was made.

The Board has failed to function properly with respect to this primary reason for its existence because it represents a negative approach to a problem that requires positive action. Negative, because the Board must await petitions to it before it can take action. Agencies are not enthusiastic about rushing to the Board when conflicts arise. They simply carry on functioning in their little compartments essentially ignoring each other. The Board should have been empowered to continuously study the system, seek out problem areas and issue authoritative policy statements. This would be a positive approach to achieving the necessary coordinated and streamlined efforts. As it is now, the decisions of the Board are recommendations with no mandatory power and the entire exercise may be made futile by their rejection by involved agencies. The Legislature while recognizing the existence of a major problem prescribed a very weak solution where a strong one was needed.

The other major function of the Water Resources Board is its responsibility for establishing and supervising *Watershed Districts* created under the Minnesota Watershed Act of 1955, Chapter 112 of the State's statutes. The decision to create Watershed Districts stemmed partly from the failure of the Drainage and Conservancy Act of 1919, Chapter 111 of the Statutes, in addition to the earlier reason given of accommodating Public Law 566 (see earlier section on the Soil and Water Conservation Commission).

The *Drainage and Conservancy Act* provided for the establishment of *Drainage and Conservancy Districts* by County District Courts upon the filing of a successful petition by residents or authorized local officials. Only ten Districts were established between 1919 and 1954, and none since. Of these two have ceased to function, four became Watershed Districts and the remaining four continue to function as Drainage and Conservancy Districts with authority to regulate streams, channels, watercourses and their flows; to provide irrigation water; control forest fires; and control floods. The Drainage and Conservancy Act represents the third example, so far mentioned, of the failure of the "petition system" to achieve desirable action, the others being with respect to the Soil and Water Conservation Districts and the functioning of the Water Resources Board. However, the system is repeated in the Watershed Act.

The *Watershed Act* gives broader powers to *Watershed Districts* than Drainage and Conservancy Districts enjoy. Additional powers include the provision and conservation of water supply for domestic, industrial, recreational, and other public uses; the regulation of waste disposal into waters; the provision and maintenance of drainage systems; the control of land and soil erosion; and the regulation of use and improvement by riparian owners of the beds, banks and shores of lakes, streams, marshes, etc., by means of permits.

The establishment of these Watershed Districts are, however, subject to the successful petitioning by counties or other local groups to the Water Resources Board. Watershed Districts are managed by three to five managers selected from ten nominees of local government units, excluding county, State and Federal officers. The managers elect a president, secretary, and treasurer from among themselves and meet annually or at other times as necessary. They are required to appoint an advisory committee to be comprised, if practicable, of a supervisor of a Soil Conservation District, a member of a County Board, a member of a sportsmen's organization, a member of a farm organization and others at the managers' discretion. The managers may employ a chief engineer, other professionals and employees. These Districts differ from the Soil and Water Conservation Districts in that they have powers of eminent domain, can levy taxes, issue bonds and can construct, operate and maintain works. In the 15 years since the passing of the Act, however, only twenty-four Watershed Districts covering an area of about one-eighth of the State's 84,068 square miles have been established, see Figure 46. Note that the Districts cover very small areas that are only minor parts of river basins and are unsuitable for meaningful water resources management. The "petition system" has again failed to produce agencies at a satisfactory rate, despite the broader powers given to the agencies.

The authorized powers of these Watershed Districts are also identical with some of those falling under the jurisdictions of the Conservation Department, Minnesota Pollution Control Agency and possibly others. Yet no clear relationship is established in the law, indicating ultimate authority or lines of delegated authority. Article 112.46 of the Statutes does require the managers of the Districts to submit their overall plans within a reasonable time after establishment to the Secretary of the Water Resources Board, with copies to the Commissioner of Conservation and his Director of the Division of Waters, Soil and Minerals. There is no requirement, however, that the Commissioner's recommendations with respect to the plans be accepted and implemented.

The overall plans are very superficial documents, describing problems in generalities often occupying single paragraphs. There is very little mention, if any, of specific projects that may or may not be initiated by the Districts. Usually landowners must request specific projects and the following statement from the summary of the Pelican River Watershed District's overall plan submitted in 1968 is typical of those made in others.

> The foregoing proposed overall plan offers a description of the District, its several problems and contains a suggestion of possible solutions. However, it must be remembered that the individual landowners in the district must, by proper petition, institute specific projects to carry out the overall plan for the district. It must also be recognized that water management beneficial to the landowner is dependent on the voluntary cooperation of each individual landowner within the district.

Once a District has been formed and plans submitted, the Water Resources Board does little else but receive and examine the District's

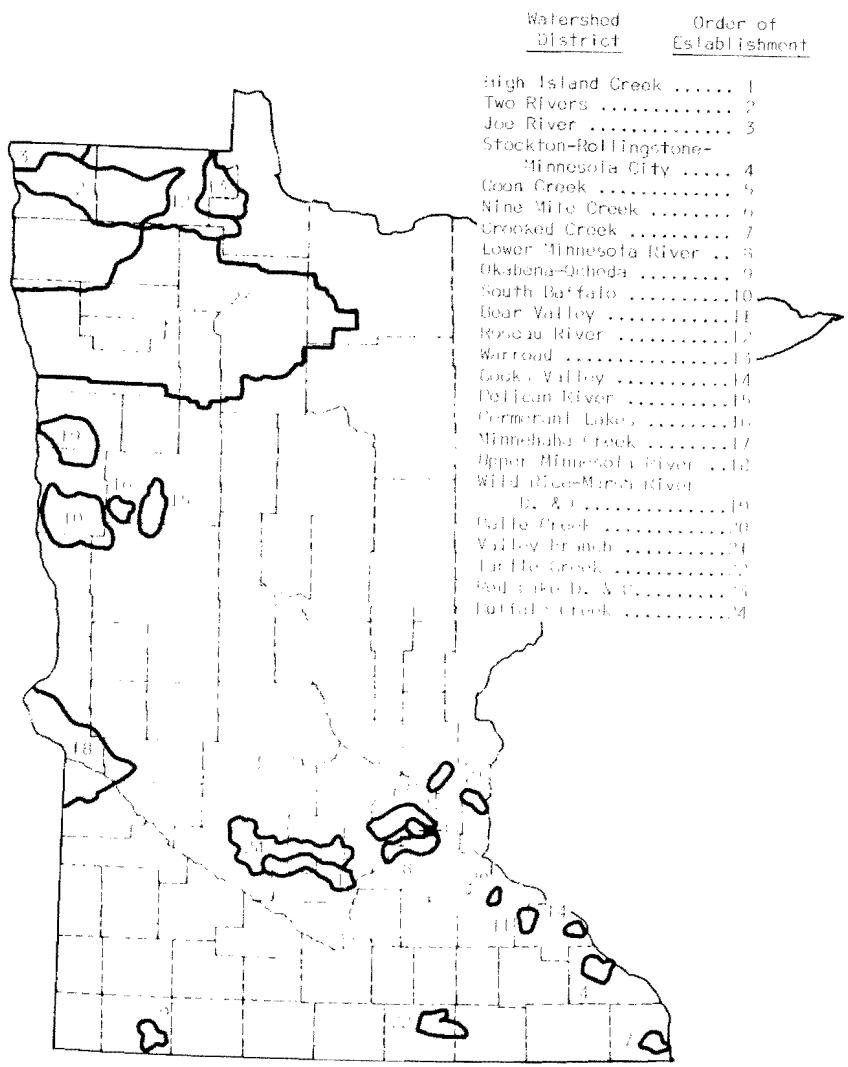

FIGURE 46. WATERSHED DISTRICTS ORGANIZED UNDER THE WATERSHED ACT IN MINNESOTA BY FEBRUARY 1969

Source: Minnesota Water Use Atlas, 1969

annual report and supervise its expenditures. Some Districts have achieved nothing since their establishment and have taken no action on their overall plans.

State Planning Agency. This Agency was created by the Legislature in 1965 as a planning agency within the executive branch of the government - under the supervision and control of the Governor - to act as a "directing, advisory, consulting and coordinating agency to harmonize activities at all levels of government, to render planning assistance to all governmental units, and to stimulate public interest and participation in the development of the state."

The Agency consists of the Governor as the State Planning Officer, a Director of Planning and other officers, employees, and agents as deemed necessary. In the interest of limiting its permanent staff, the Agency is required to contract for basic research, employ consultants and utilize the facilities of State departments, agencies and the University of Minnesota. The staffing includes a Natural Resources Planning Director.

The objectives of the Agency are to be met by:

(a) Relating the planning activities of various State agencies to one another.

(b) Stimulating and assisting the planning programs of State agencies.

(c) Providing a creative level of planning for the exploration of alternative means of achieving goals (104).

The Agency's planning will set a series of functional plans (transportation, natural resource development, etc.) within the broad framework of a comprehensive policies plan. The functional plans will in turn establish the framework within which State and local agencies would develop their programs (104).

A Water Resources Coordinating Committee (Figure 47) was established in 1967 under the supervision and control of the Natural Resources Planning Director, This Committee is providing liaison with State, Federal, local, and private organizations; participating in Federal, Federal-State and interstate water resources planning; and developing a comprehensive water and related land resources plan. This Committee functions primarily in an advisory capacity (104).

The Committee's work on the development of a comprehensive Statewide water resources plan is the first of its type in the State. With the help of a task force it has completed a compilation of background information for framework water resources planning in the State (23). The first assessment of that information is also completed (89). This framework (Type I) plan provides a broad guide for the best use of the resources and includes no formulated projects. It will be followed by a Type II plan which will define and evaluate projects.

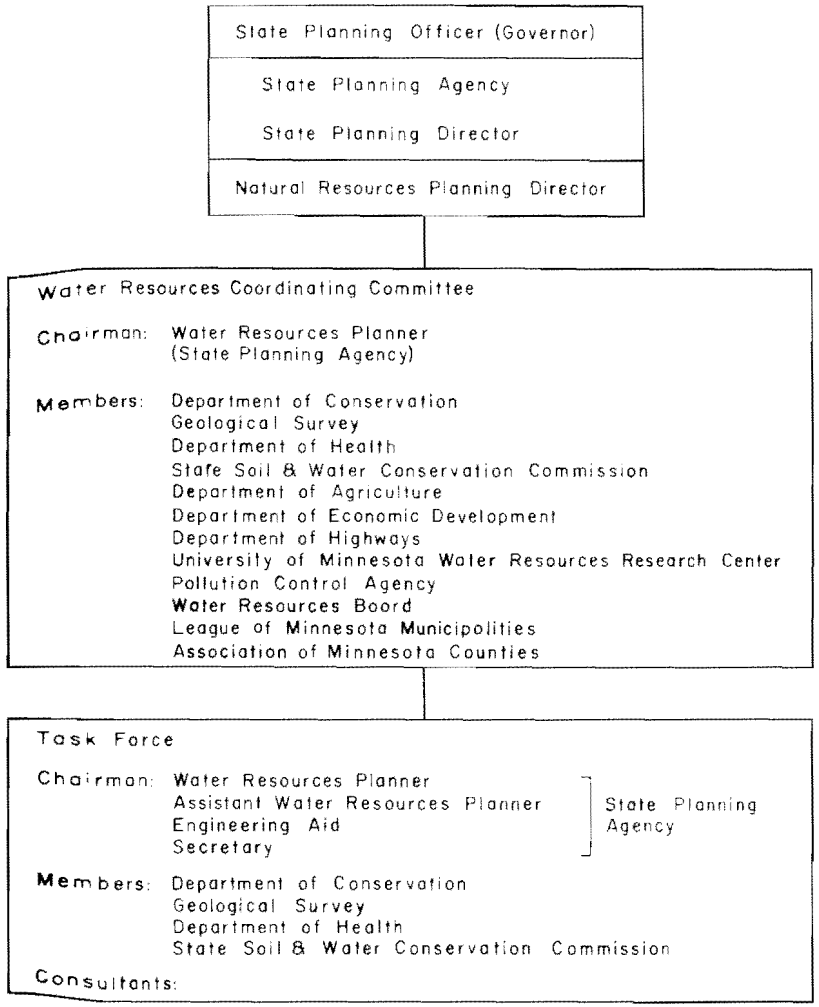

FIGURE 47. ORGANIZATION OF THE WATER RESOURCES COORDINATING COMMITTEE, MINNESOTA STATE PLANNING AGENCY (104)

The Committee has been participating simultaneously with its own planning activities in those of the Souris-Red-Rainy River Basins Commission, the Great Lakes Basin Commission, the Upper Mississippi River Comprehensive Basin Study Coordinating Committee; and the Missouri Basin Inter-Agency Committee.

The State Planning Agency has also been instrumental in fostering regional planning and the establishment of eleven planning and development regions in the State. The Agency's efforts are not pioneering since the Minnesota Joint Powers Act of 1943 permits any two units of government to do jointly things each can do individually, including planning. The more than one hundred and fifty sub-state regional delineations, however, indicated to Hoyt (105) that regional development may be better served by the establishment of a relatively common set of delineations. Further impetus came from the President's memorandum of September 2, 1966 to Federal departments, and the Bureau of the Budget Circular A-80 that followed, both requiring Federal agencies to operate their programs only through State established planning districts and regions except where there is clear justification for doing otherwise. Based on research undertaken by the University of Minnesota (105), the Agency made recommendations to the Governor and the Legislature in 1968 that resulted in the issuing of Executive Order No. 37 dated April 3, 1969, and the passing of the Regional Development Act of 1969, Chapter 1122 of Minnesota Statutes (106).

The purpose of the Executive Order is to provide a uniform geographic framework for:

(a) The collection and classification of data for state, local and regional planning.
(b) The coordination of state, regional and local planning activities.
(c) The coordination of federall sponsored or operated programs at the regional level within Minnesota.
(d) The coordination and unifying of local resources for resolving local problems and exploiting opportunities.
(e) Providing a framework for the organization of local government for intergovernmental cooperation and planning.

The Order designates the eleven planning and development regions shown in Figure 48 as the official regional structure of the State. The transitional counties are to remain such for a twelve month period following the effective date of the Order (April 3, 1969) at the end of which the Governor will make final regional assignments based on the findings of public meetings held in the counties. The boundaries are to be under continuing review and subject to changes as necessary. All State departments and agencies are to utilize the regions for all planning purposes and may combine two or more as deemed necessary.

The Act authorizes the establishment of Regional Development Commissions with jurisdictions coterminous with the regions of the Order. These Commissions are to be established by petition of local units or by the Governor's initiative. This seems to recognize the past failures of the "petition system," discussed earlier, in achieving desirable ends in

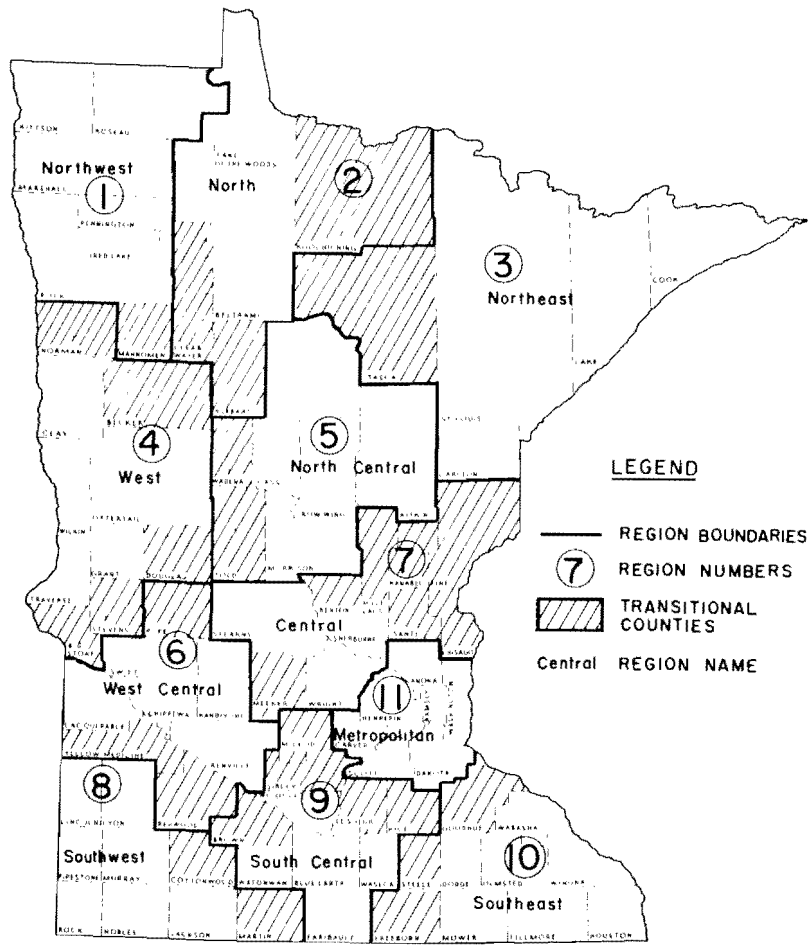

FIGURE 48. PLANNING AND DEVELOPMENT REGIONS OF MINNESOTA (106)

reasonable time, if at all. The Governor can, in this case, establish the Commissions on his own initiative should petitions not materialize. This is desirable for prompt action. The Commissions will be composed of representatives of local government and citizens at large with an even balance between municipal and county officials. Excluding citizen membership (to be decided by the Commissions), the Commissions would range in size from fifteen to thirty-three. The Governor as State Planning Officer may appoint ex officio members of each Commission, without voting powers. He also appoints the Chairman of each Commission who must be a resident of the region. Each Commission appoints its Executive Director from among the citizens of the nation at large on the recommendations of its Chairman. Staff is to be appointed by the Chairman with the approval of the Commission.

The mandatory duties and functions of the Commission are (106, p. 22):

> (a) The development of a comprehensive plan for a region;
> (b) Review of long term comprehensive plans of local government units within the region;
> (c) Preview of similar plans of independent boards or commissions within the region;
> (d) The review of applications of governmental units for loans and grants from the United States of America, or from the state whether or not such a review is required by the federal government.

The plan review contemplated by the Act is meant to be in the form of comment only and not a veto (106). The Act provides, under subdivision 2, however, for the indefinite suspension of plans which are inconsistent with the Commissions' comprehensive plans and for the State Planning Officer (Governor) to consider and dispose of disagreeing positions (106).

Other authorized activities of Commissions include, urban, rural, and other types of research; feasibility studies of programs related to water, land use, economic development and other problems of regional concern; civil defense and flood plain management. The Commissions may appoint members to serve on sub-regional planning boards and other special districts within their regions.

The Commissions are to be financed from Federal-regional planning grants, State grants-in-aid, and region-wide tax levies.

Local agencies. Earlier mention has already been made of the function of county boards and district courts in financing and executing works for the Soil and Water Conservation Districts and Watershed Districts. Other local governmental units such as municipalities and village councils have responsibilities for regulating the waters within their boundaries and the pollution of those waters. County and other local governments control land use by general zoning ordinances and some are currently planning flood plain zoning ordinances.

Two local regional bodies are worth specific reference. These are the Minneapolis-St. Paul Sanitary District (MSSD) and the Metropolitan Council.

The *Minneapolis-St. Paul Sanitary District* (MSSD) was created in 1933 under Chapter 445 of the Minnesota Statutes. This is an entirely different chapter to that mentioned earlier (Chapter 115) under which Sanitary Districts were established following petitions to the Water Pollution Control Commission now the Minnesota Pollution Control Agency. Here we have Sanitary Districts being set up essentially for a similar reason - the control of waste disposal into streams in the interest of public health - but under two different laws and administered by two different agencies. In the case of Chapter 445, it is the State Board of Health that determines whether such Districts are necessary (no petitions required) and following such a determination is empowered to establish them. This Chapter applies to cities of the "first class" while Chapter 115 may only apply to such cities with the approval of their governing bodies. Such varying arrangements can only serve to add complexity.

The MSSD's seven-member governing Board of Trustees is comprised of the mayor, a council member, and a citizen of each city, Minneapolis and St. Paul, appointed by its council, together with a member appointed by the Governor from the State excluding Hennepin and Ramsey counties in which the cities are situated. In addition to the power to construct and maintain waste disposal systems, the District is authorized to regulate and control the discharge of wastes from industries in its jurisdictional area. The question may again be asked, what is the relationship of this regulatory authority to that of the Minnesota Pollution Control Agency? The District may also contract with adjacent municipalities, villages, etc., for the disposal of their sewage and industrial wastes. The primary sewage treatment plant operated by the District at Pig's Eye on the Mississippi River since 1938 was expanded to provide secondary treatment in 1968. With its capacity increased to 218 million gallons a day, the plant now serves 1,300,000 people in forty-nine metropolitan communities and agencies.

The *Metropolitan Council* was created in 1967 under Chapter 473B of the Minnesota Statutes for the purpose of coordinating planning and development of the seven county Metropolitan Area consisting of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington Counties. It is a fifteen member council appointed by the Governor, one member to be chosen from each of fourteen districts, and the chairman from anywhere within the entire Area.

The Council has powers to review all long-term comprehensive plans with area-wide effect of independent commissions, boards, or agencies for consistency with its own regional comprehensive plan before execution of those plans. Inconsistent plans are to be indefinitely suspended until differences are settled, failing which these differences are to be submitted to the next regular session of the Legislature for its disposition. When required by Federal law or a Federal agency, the Council is empowered to review all applications of governmental units, independent commissions, boards or agencies operating in the Metropolitan Area for U. S. Government loans or grants. The Council's comments and recommendations are forwarded with the application.

As created in 1967, the Metropolitan Council had no jurisdiction over the operations of the Minneapolis-St. Paul Sanitary District or those of any Sanitary Sewer District operating within the Metropolitan Area. The Council was, however, authorized by the Metropolitan Sewer Act of 1969, Chapter 449 of the Minnesota Statutes to create a sewer service board and with it "take over, acquire, construct, operate, and maintain all interceptors and treatment works necessary for the collection, treatment and disposal of sewage in the metropolitan area." The *Metropolitan Sewer Board* thus created must appropriately acquire by January 1, 1971 all the works and other interests of the MSSD, and the North Suburban Sanitary Sewer District and any other similar ones created under Minnesota Statutes, Section 471.59.

The Metropolitan Sewer Board is comprised of seven members appointed by the Metropolitan Council, one from each of seven precincts of the Metropolitan Area. Members serve staggered four year terms. They appoint a Chairman from among themselves, and a Chief Administrator who attends all Board meetings but has no vote. The Board with the Council's approval must establish, after public hearing, *Sewer Service Areas* to be served by a particular interceptor or group of interceptors. The governmental units in each such Area may establish an *Advisory Board* comprised of not more than five members, one to be appointed by each of the five most populous municipalities in the Area.

It is the Metropolitan Sewer Board's responsibility to administer the comprehensive plan adopted by the Council for the collection, treatment, and disposal of all sewage (water-carried wastes of all types) in the Metropolitan Area. All local governmental units in the Metropolitan Area are required to develop similar comprehensive plans for coordination with the Council's plan. The plans of local governmental units must be approved and amended as required by the Board before any substantial works are undertaken. The Board may require any person or local government to provide for the discharge of its sewage, directly or indirectly into the Board's disposal system. It may also adopt rules and regulations governing the operation of its works, and provide penalties for violation of those rules.

The Metropolitan Sewer Act provides for the allocation of the Board's current operation costs among local governmental units in proportion to the volume discharged by each unit adjusted for strength of the discharge and other factors. Outstanding payments can be recovered from local governmental units by means of deficiency tax levies. The Council may authorize the issuance of general obligation bonds for the acquisition or betterment of sewage works, and certificates of indebtedness in anticipation of revenues to be collected in the current budget year. The Council may also receive advances of up to $500,000 from the State general revenue fund to be repaid with six percent annual interest. The Council or Board with the Council's consent may accept gifts, and may apply for and accept grants or loans from the United States, the State or individuals for any of the Council's (or Board's) purposes.

Local governmental units and the Commissioners of Highways and Conservation are authorized to convey or permit the use of their facilities by the Council or the Board. The Board may construct and maintain its

systems or facilities in, along, under, over, or through public streets, bridges, etc. without first obtaining a franchise from any local governmental unit but must do so in accordance with the appropriate local government ordinances and resolutions. Discharges from the Board's treatment works into waters of the State must be in compliance with the standards adopted by the Minnesota Pollution Control Agency.

Except for the references made in the previous paragraph to the Commissioners of Highways and Conservation, and the MPCA, relationships between the Metropolitan Council and State agencies are not specified in the laws. No lines of authority have been established and consequently some confusion exists. Also the Council does not have the same authority to enforce comprehensive plans in other areas of its activities as it does for sewage disposal. Its authority in most other areas is limited to the adoption of "development guides" and the making of advisory comments on plans of local governmental units. An example of the type of confusion that stems from such a system is given below.

The President of the Minnehaha Creek Watershed District has recently raised the issue of final authority with respect to the District's plan for development of the Minnehaha Creek area submitted to the Water Resources Board and the Council for review (107). In this case, the Board approved the plan but the Council has suspended part of it and the President of the District has indicated that a ruling of the courts may be necessary. This is an example of the type of confusion that arises from a highly fragmented administrative system in which there are no clearly stated lines of authority and no single agency of ultimate jurisdiction.

Reference has been made to the Regional Development Commissions to be created under the Regional Development Act of 1969 (106). One of these Commissions is to have jurisdiction over the Metropolitan Area which is precisely the area in which the Metropolitan Council functions. The responsibilities and functions of the Council and the proposed Commission are almost identical. What then is to become of the Council? Presumably it will become the Commission for the Metropolitan Area, Region 11 in Figure 48. The Regional Development Act does not answer this question. There are significant differences in some features of the proposed Commissions and the Council. While the Commissions are to be responsible to the Governor with respect to the disposition of their disputed decisions, the Council is responsible to the State Legislature. Representation on the two bodies also differ. Further, while the Commissions are specifically authorized to "prepare and adopt ... a comprehensive development plan for the region" (106, p. 39), the Council is authorized to develop "long range planning *in* the metropolitan area but *not for* the metropolitan area," except with respect to sewage disposal. Consideration must be given to reconciling these differences if the Council is to function as the Commission in Region 11. If, however, it is not, then there will be another case of two agencies serving similar purposes in a single area. This can only add to the problems of an already confusing situation.

Federal agencies. Walton (108) lists and describes the activities of thirty-one Federal organizations with responsibilities in water and related land resources in Minnesota. Twenty-three of these agencies are

in seven Cabinet departments, five are independent agencies, and three operate within the Executive Office of the President. These agencies are all depicted in the organizational chart shown in Figure 49.

The *Department of Agriculture* is mainly concerned with aid to farmers for erosion control, soil and water conservation; water supply and sewerage facilities on farms and in rural communities; flood prevention and control; and watershed management in national forests.

The *Department of Commerce* provides aid for water supply and sewerage systems, flood protective works, recreation facilities, and other water resources activities; hydro-meteorological services including weather forecasts; economic analyses; and statistical services.

The *Department of Defense* through the *Corps of Engineers* participates in comprehensive river basin planning under the Water Resources Planning Act of 1965, Public Law 89-80; executes water resources development projects of all types including flood control, navigation, power, water supply, water quality control, recreation and fish and wildlife enhancement; and provides assistance at times of major disaster. A summary of the Corps' activities in the State is to be found in reference (87).

The *Department of Health, Education, and Welfare* through the *Public Health Service* exercises overall responsibility for the public health aspects of river basin planning and development; regulates the water supplies of interstate carriers; plans emergency public water supplies; supports State water supply planning and programming activities; and provides grants for water supply, sewerage and storm drainage in urban development.

The *Department of the Interior* has the widest range of activities undertaken by fifteen separate agencies. These activities include support of water resources research; policy making with respect to fish propagation and wildlife enhancement; geological and hydrological surveys, and water quality analyses; drainage, irrigation, and other water resources activities on Indian reservations; management of the resources, including water, of Federal lands; management of government owned recreational areas and preservation of historic sites; and the administration, through the *Federal Water Pollution Control Administration* (FWPCA), of the Water Quality Act of 1965, Public Law 89-234, and other related acts aimed at establishing a national policy for pollution control.

In the *Executive Office of the President* budgetary control of Federal programs is exercised by the *Bureau of the Budget*; the *Office of Emergency Planning* administers Federal disaster assistance programs; and the *Office of Science and Technology* provides staff services for the *Council for Science and Technology* which is charged with recommending policies, identifying research needs, making effective use of scientific and technological resources, and furthering international cooperation in science and technology.

The *Atomic Energy Commission* (AEC) is responsible for the protection of the public's health and safety through the regulation of the use of source, by-product, and special radioactive materials. In particular,

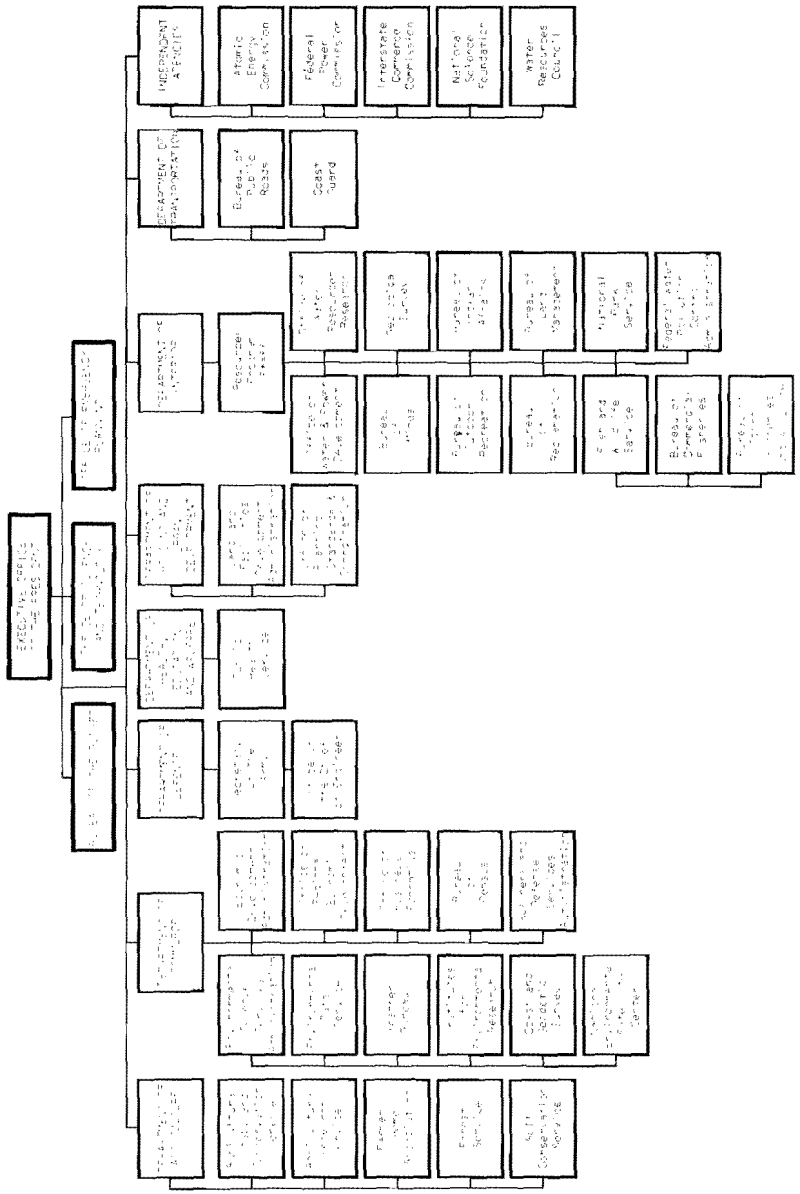

FIGURE 49. FEDERAL AGENCIES CONCERNED WITH WATER AND RELATED LAND RESOURCES PLANNING IN MINNESOTA (108)

it regulates the nuclear power industry and monitors the environment of nuclear power plants.

The *Federal Power Commission* investigates and evaluates hydroelectric power sources and regulates the development of such power.

The *Interstate Commerce Commission* exercises jurisdiction over water carriers on inland rivers, the Great Lakes and coastal waters.

The *National Science Foundation* administers research and educational grants for hydrological and other water related studies.

The *Water Resources Council* exercises jurisdiction over comprehensive inter-agency regional and river basin planning under the Water Resources Planning Act of 1965, Public Law 89-80. It coordinates such planning programs and assists States financially in participating in them.

Interstate and international agencies. Minnesota, in recognition of its many interstate and internationally shared waters has participated and continues to do so in many interstate and international organizations. These organizations are essentially advisory in nature, developing and coordinating plans which participating States are expected to follow.

The Federal Government's increased interest in comprehensive river basin planning during the last decade found expression in the Senate Document No. 97, 87th Congress, 2nd Session. This document is the basis for planning being undertaken by a number of river basin inter-agency committees, and the basin commissions established under the Water Resources Planning Act of 1965, Public Law 89-80. The four agencies functioning on this basis with respect to Minnesota's waters are the *Souris-Red-Rainy River Basins Commission* and the *Great Lakes Basin Commission* established under the Water Resources Planning Act of 1965; the *Upper Mississippi River Comprehensive Basin Study Coordinating Committee* established in 1963; and the *Missouri Basin Inter-Agency Committee* established in 1954. The jurisdictional areas of these agencies are as shown in Figure 14. The Federal Government participates jointly with the basin States in these agencies, with the U. S. Army Corps of Engineers playing a major role particularly in the preparation of the comprehensive plans. The two basin commissions are charged with preparing and keeping up-to-date joint plans for Federal, State, interstate, local and non-governmental development of water and related resources in their basins. The Upper Mississippi River Comprehensive Basin Study is developing a framework plan to serve as a broad guide to the best use or combination of uses of the water and related land resources of the region. The Missouri Basin Inter-Agency Committee's primary mission is the coordination and programming of State and Federal activities and the development of a framework type of plan for the basin's water and related resources. Minnesota's representation on these agencies has come from the State Planning Agency. The Missouri and Upper Mississippi River Basins framework plans were completed in fiscal year 1969 while those for the Great Lakes and Souris-Red-Rainy are due in fiscal year 1971 (23).

Other interstate agencies with Federal participation in which Minnesota is represented include the *Upper Great Lakes Regional Commission*

and the *Mississippi Parkway Planning Commission*.

Minnesota is also represented on the following interstate agencies on which there are no Federal representatives: the *Great Lakes Commission*; the *Minnesota-Wisconsin Boundary Area Commission*; the *Mississippi River Parkway Commission*; the *South Dakota-Minnesota Boundary Waters Commission*; the *Missouri Basin Inter-Agency Committee - State's Committee*; and the *Tri-State Waters Commission* (with North Dakota and South Dakota) which hasn't functioned since 1949.

The State's interests are represented by the Federal Government on the *International Joint Commission* established jointly by the United States and Canada to adjudicate questions pertaining to the use of the boundary waters of the two countries.

Jurisdictional confusion among agencies. Reference has already been made to the absence of clear lines of authority among State and other agencies with identical or similar functional responsibilities, and coinciding or overlapping areal jurisdictions. The undefined relationships between the Department of Conservation and the Minnesota Pollution Control Agency on the one hand, and the Watershed Districts and Soil Conservation Districts on the other, constitute an example. The difficulty of the Minnehaha Creek Watershed District in determining whether the Water Resources Board or the Metropolitan Council has final authority over the District's operations is another. Yet another concerns the authorization of both the State Board of Health and the Minnesota Pollution Control Agency to administer the establishment and operation of Sanitary Districts.

Two more examples of jurisdictional confusion among agencies are worth mentioning. The first refers to the *Alma Barge Accident* of June 1969 which shows clearly the indecision and inaction that occur during emergencies under systems of fragmented responsibilities. A barge containing fuel oil became grounded on the wing dam just north of Alma, Wisconsin, 50 miles downstream of the Twin Cities on the Mississippi River at 12:10 a.m. on Monday, June 16, 1969, spilling its contents into the river. A report was made to the U. S. Coast Guard within two hours but corrective action never got started for 53 hours by which time 64,000 gallons of oil had spread itself thin for a considerable distance along the river. The Coast Guard and the Corps of Engineers were reportedly reluctant to act in the absence of specific authority while the Federal Water Pollution Control Administration (FWPCA) is only authorized to coordinate such action (109). The Director of the Division of Water Quality of the Minnesota Pollution Control Agency (MPCA) indicated at a personal interview that no State agency had authority to act in such a matter. It is not known why the Wisconsin authorities also failed to act. Finally the Corps of Engineers acted to remove the oil upon the request of the FWPCA on Wednesday, June 18, 1969. Even allowing for the delay in determining that the spill was serious, too long a period elapsed before cleaning operations began. It is a serious indictment of the State's administrative system that no State agency had the authority to act, assuming the claim to be true. State and Federal agencies have since been cooperating on the development of a plan of action for use in such emergencies.

The second example concerns the law suit brought by Burnsville and Egan Township against the Lower Minnesota River Watershed District in the Dakota County District Court to invalidate the District's flood plain zoning regulations (110). The municipalities argued that they alone have authority to control construction within their boundaries but the judge's ruling favored the District, pointing to the specific authority in the Watershed Act for the regulation of flood plain construction. The confusion, however, arises because more than one agency, organization and/or governmental unit are authorized to perform functions without any reference to a prevailing authority. Not only is there confusion among agencies but also among the public who are left to wonder whose set of regulations should be followed. The judge didn't seem to rule on this last mentioned point but simply on the fact that the Watershed District is authorized to regulate flood plain construction and that its regulations are reasonable.

Comparison with the institutional criteria. The following comparison of the arrangements for water resources management in Minnesota with the institutional criteria developed in Chapter 3 indicates the existence of significant deficiencies with respect to each criterion.

The extent of governmental involvement particularly through State institutions is essentially limited to resource intelligence, planning and regulation with very little activity of a developmental nature, or in regional distribution and disposal. Even with respect to those activities undertaken, the full range of alternatives available are not used. Until the very recent establishment of the State Planning Agency, and the Federal-State planning commissions and committees, truly comprehensive long-term planning has been absent. Data collection and particularly data processing leave much to be desired. Much water use and water quality data collected by the major agencies are not processed and available for use in day-to-day decision-making nor even for long-term planning in many cases. Integrated water resources management (including water quality management) requires the functioning of governmental institutions through all stages of Craine's involvement chart described in Chapter 2.

The second criterion pertaining to the adjustment of externalities cannot be met under the present arrangements where responsibilities are fragmented among many agencies; where watershed units are so small as to be ineffective and in any case do not cover entire hydrologic units; and where there are no legal and administrative requirements for the exchange of payments among water use and development agencies in accordance with spillover damage or beneficial effects.

Departments are not always free to adapt their management decisions to different circumstances as required by the third criterion. The Legislature has from time to time passed laws restricting the Commissioner of Conservation's powers with respect to the issuance of permits for water extraction and use. Examples are the 1965 law that allowed the City of Cloquet to appropriate and use water from Lake Superior without the need for a permit; and the laws varying the permit system to allow more assured rights for water users in the mining industry than apply to other users, see Haik et. al (21). On the other hand, as has been

pointed out in the same source, the Department of Conservation has seemingly arbitrarily limited appropriations for irrigation to six inches of water per acre per year; prohibited the assignment of water rights and the transportation of appropriated water; and set limitations on what constitutes riparian lands. The important balance between flexibility and stability seems to be lacking. Furthermore, the main source of public influence in management decisions is through hearings. Where policy making boards exist, in many cases they are not truly representative and are selected by politicians without affording interest groups and public sectors the opportunity to nominate their own representatives. While public hearings could be useful tools for determining public opinion they should not be used as a replacement for direct public access to decision-making boards and committees.

The ability to express and consider the range of values relevant to management decisions is severely limited by the jurisdictional fragmentation among agencies. Formal interagency review procedures are either non-existent or inadequate except for the Agreement between the Department of Health and the Minnesota Pollution Control Agency, and for the recent efforts of the State Planning Agency in bringing departmental heads together for long-term comprehensive planning. The weaknesses of public representation earlier mentioned also applies to this criterion. There are weaknesses pertaining to decision making rules which have been discussed by Haik et al. (21) with respect to the operation of the water appropriation permit system by the Department of Conservation. This Department has no set of published rules, regulations or criteria for evaluating applications.

With respect to the criterion pertaining to the ability to finance water management consistent with the objective of efficiency, reference has been made to the limited activities of agencies such as the Department of Conservation and the Minnesota Pollution Control Agency stemming from inadequate financing. The latter agency has recently had consultants recommend ways of improving its financing (101). Sources of revenue such as abstraction and effluent charges are not used and agencies must generally depend on Legislative appropriations, grants, and subsidies.

The sixth criterion is concerned with the extent to which water management is recognized and built into government as a continuing function. There is still the tendency towards ad hoc arrangements that do not lead to permanent legal and administrative measures. A relevant question is how permanent is the Water Resources Coordinating Committee and, stemming from this, what will happen to the comprehensive plan it is developing, upon the completion of the plan? What are the permanent arrangements being made to ensure the implementation of the plan and its continued up-dating? While it is possible that the Committee may be kept functioning indefinitely to revise the plan as needed, no agency is currently known to have the power to enforce its implementation.

The last criterion pertaining to the ability to account for environmental interrelationships has been receiving some recent recognition in the State. The replacing of the old Water Pollution Control Commission by the Minnesota Pollution Control Agency (MPCA) with broader powers including the control of air pollution and solid waste disposal is an example of this recognition. The interrelationships will presumably be

accounted for by handling within a single agency. The MPCA has also recognized that land use management is of importance and has commissioned a study by consultants (100). The Department of Conservation has also recently been preparing shoreland and flood plain zoning regulations which are likely to be fully operative within the next two years. The lack of, and need for, land use management that is relevant to water quality management (and water resources management) in the State has been very strongly attributed to by the findings of Borchert et. al (110) in their recent lakeshore study. Similar findings would no doubt result from similar studies of the State's other water resources. The effect of suburban and other unsewered development on the ground-water quality has already been mentioned earlier in this chapter, and so has the effect of run-off from agricultural lands into the Minnesota and other rivers.

VII. SUMMARY

In summary, the following conclusions can be drawn about Minnesota's water resources and their management:

1. The resources are relatively vast in comparison with those of most other States and more than adequate to meet present needs.

2. Population growth and the "burgeoning urban-industrial-agricultural economy" of the State are, however, placing rapidly increasing demands on these resources.

3. Concern has been expressed that problems will arise in many areas of the State - mainly the most populous and industrialized - as early as 1980 due to the full use of available quantities of water. Of even greater concern should be the fact that poor water quality has already limited and restricted many water uses in these areas and will further limit the use of available quantities of water in the absence of improved and adequate water quality management.

4. Water quality management is almost entirely limited to pollution control characterized by the use of effluent and stream standards to control waste discharges to waters. Absent are the wide variety of measures to improve the assimilative capacity of waters and the use of economic incentives to force optimum water use and the reduction of waste discharges.

5. Water quality management has not been playing the role it should in decision-making relative to the use of the State's water resources. Its role in water resources management should be a central one providing stimulus to optimal water (and related land) resources use.

6. Water resources management in the State is characterized by a highly fragmented administrative system, the result of an ad hoc approach rather than truly planned growth. Evidences of conflicts and unnecessary duplication are to be found together with jurisdictional confusion among agencies.

7. Water resources management in the State is significantly deficient with respect to all of the seven criteria for management institutions developed in Chapter 3.

CHAPTER 5

PROPOSALS FOR INTEGRATED WATER RESOURCES MANAGEMENT IN MINNESOTA

The purpose of this chapter is the development of alternative proposals for integrated water resources management of the form described in Chapters 2 and 3. In doing so, the extent and form of regional decentralization is first examined. Alternative institutional arrangements are then proposed and policies suggested for consideration and adoption. An attempt is made to fit the proposals not only to the physical characteristics and problems associated with the State's water resources but, importantly, to the prevailing governmental system.

I. REGIONAL DELINEATION

At issue here is the choice of a set (or sets) of regional jurisdictions that would lend itself (themselves) to efficient management of Minnesota's water resources. The earlier chapters indicate that two types of regions should be considered. In Chapter 2 it is pointed out that from the points of view of managing productive capacity, water quality, and hydrologic interdependencies, hydrologic units (and/or subunits) should form the bases of regional water resources management. However, consideration must also be given to the constraints of the Regional Development Act of 1969, Section 6 of which requires that

> all coordination, planning, and development regions assisted or created by the State of Minnesota...shall conform to the regions designated by the executive order [Executive Order No. 37 of 1969] except where, after review and approval by the State Planning Officer [Governor], nonconformance is clearly justified.

The approach used is, therefore, one of choosing a "best" set of hydrologic units, and examining it for compatibility with the eleven development regions discussed in Chapter 4 and also for the advisability of using the latter regions (or combinations of them) as the basis of water resources management.

Hydrologic Units

As shown in Figure 17, the State is divided into three major drainage basins: the Souris-Red-Rainy River Basins draining northwards to the Hudson Bay; the Great Lakes Basin draining eastward; and the Mississippi River Basin draining southward to the Gulf of Mexico. What further subdividing of these major basins are considered necessary to facilitate management of the water and related land resources?

On examining the Souris-Red-Rainy drainage system it is seen that a number of reasons point to its sub-division for management purposes. Of the three river basins, only two - the Red River of the North and the Rainy River basins - are contained (partly) in Minnesota. Firstly, these two basins drain independently into Canada. Secondly, their physical characteristics are significantly different with the relatively low

and gently sloping basin of the Red River contrasting with the higher, rapidly sloping basin of the Rainy River, characterized by its irregularly shaped lakes and short connecting streams. Further the highly fertile plains of the Red River Basin are renowned for their agricultural products while the densely forested watershed of the Rainy River and its many lakes are of major importance because of their scenic beauty and recreational value. The water use characteristics, pollution and other water related problems are also significantly different, as the descriptions in Chapter 4 indicate. It is, therefore, felt that the Red River of the North and the Rainy River basins should be in separate management regions.

The Great Lakes Basin including the St. Louis River Basin is considered homogeneous enough to warrant no subdivision for management purposes.

The Mississippi River Basin in Minnesota is considered large enough to be divided into at least two management regions. The Minnesota River, the major tributary of the basin, can be placed in a management region of its own with arrangements (to be discussed later) made for taking care of the hydrologic interdependencies of the entire basin. Indeed the Minnesota River Basin exhibits some significant differences from that of the main stem of the Mississippi River. The Minnesota River slopes much more gently, is more subject to flooding, has different water use demands and pollution problems (greater fertility and algal growths for instance), and different ground-water basin characteristics. Though the problems of the Mississippi Main Stem are many it is felt that they can be managed in conjunction with those of the St. Croix River. Similarly the very small section of the Missouri and Des Moines River Basins in Minnesota can be managed in conjunction with the Minnesota River Basin. The Mississippi River Basin would thus be divided into two management regions: the Mississippi River Main Stem Region including the St. Croix River Basin, and the Minnesota River Basin Region including the Missouri and Des Moines River Basins.

In accordance with the above, the State would be divided into five management regions as shown in Figure 50. Consideration has been given to the possible use of the thirty-nine watershed units shown in Figure 24 but it is felt that this would be more difficult to coordinate satisfactorily and result in much less efficiency than the five-region system. The units of the proposed five-region system are considered small enough to bring the management agencies close enough to their problems, while at the same time being sufficiently large to permit efficient management and meeting of the criteria (see Chapter 3) with respect to internalizing the externalities and accounting for the hydrologic interdependencies.

The apparent neglect of ground-water aquifers in the above considerations is due to the lack of pertinent information. The areal extent of the major aquifers and their natural recharge and discharge areas have not been adequately determined. Much is also unknown about the hydrologic links between these aquifers and the surface water basins. The administrative arrangements to be developed would be such that the hydrologic interdependencies between ground and surface waters of the State could be accounted for by means of centralized control and systems of exchange payments.

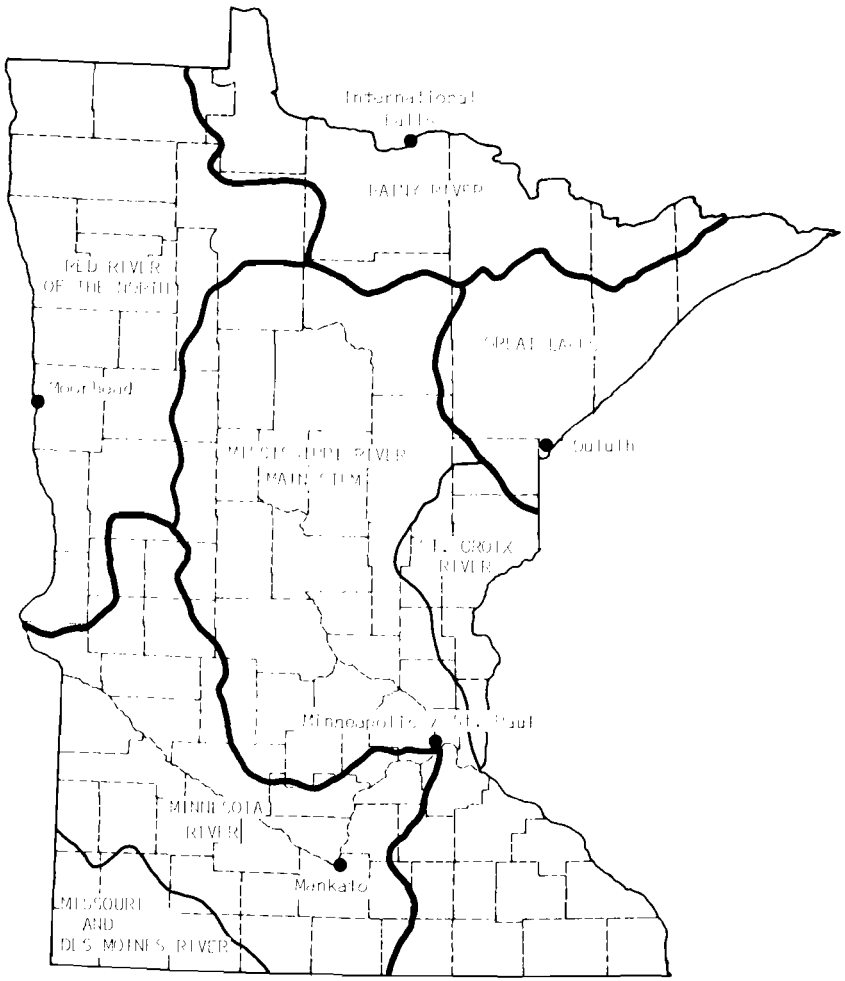

FIGURE 50. PROPOSED HYDROLOGICALLY BASED WATER MANAGEMENT REGIONS OF MINNESOTA

Regional Development Units

The five hydrologically based regions together with the eleven Planning and Development Regions are shown in Figure 51. An examination of this figure indicates the problems that would arise from the use of the Development Regions for water resources management. The Northeast Development Region, No. 3, is seen to include almost all of the Great Lakes Basin and about one-half of the Rainy River Basin. Depending upon the final placing of the transition counties, this Northeast Region may yet include more of the Rainy River Basin and substantial portions of the Mississippi River Basin. No possible variations of the boundaries of the Northeast Region based on county limits could avoid the unsatisfactory fragmentation of the Rainy River Basin and the inclusion of at least two and possibly three distinctly different hydrologic units in the region. This would be most undesirable for managing the production capacities of the hydrologic units and for taking care of the hydrologic interdependencies. Similarly the North Development Region, No. 2, regardless of the final placement of transitional counties will contain substantial portions of the Red River and Rainy River Basins and at least the source of the Mississippi River. It, therefore, seems reasonable to conclude that the Development Regions do not form a reasonable basis for the management of the State's water resources. It should accordingly be possible to successfully claim the "nonconformance" exception under Section 6 of the Regional Development Act earlier quoted. The principles and spirit of the Act, it must be pointed out, can be adequately met and promoted by representation of the Regional Commissions on the water management boards and committees to be discussed in the next section.

In summary, it is desirable to use hydrologic units as the basis for regional management of Minnesota's water resources. Five such units are proposed, namely: the Red River of the North Basin; the Rainy River Basin; the Great Lakes Basin; the Mississippi Main Stem River Basin; and the Minnesota River Basin as shown in Figure 50. The use of these river basins for regional management would be in conformance with the policy of the Federal Government to foster regional river basin planning and development through the Water Resources Planning Act of 1965, Public Law 89-80, and also with the joint Federal-State comprehensive river basin planning now in progress under that Act.

II. INSTITUTIONAL ARRANGEMENTS

Three alternative institutional arrangements are proposed for the management of Minnesota's water and related resources with water quality management a fully integral part of each. The alternatives are not necessarily arranged in any order of preference but mainly in ascending order of the magnitude of change from the present situation that would be required for their implementation.

Common to all the proposals is the increased public representation on the decision-making bodies of State and regional agencies. This would give the public, including local governments and special interest groups direct input to the formulation and consideration of alternative proposals, and really active participation in decision-making. It would answer the often expressed claim of the public of being excluded from the early

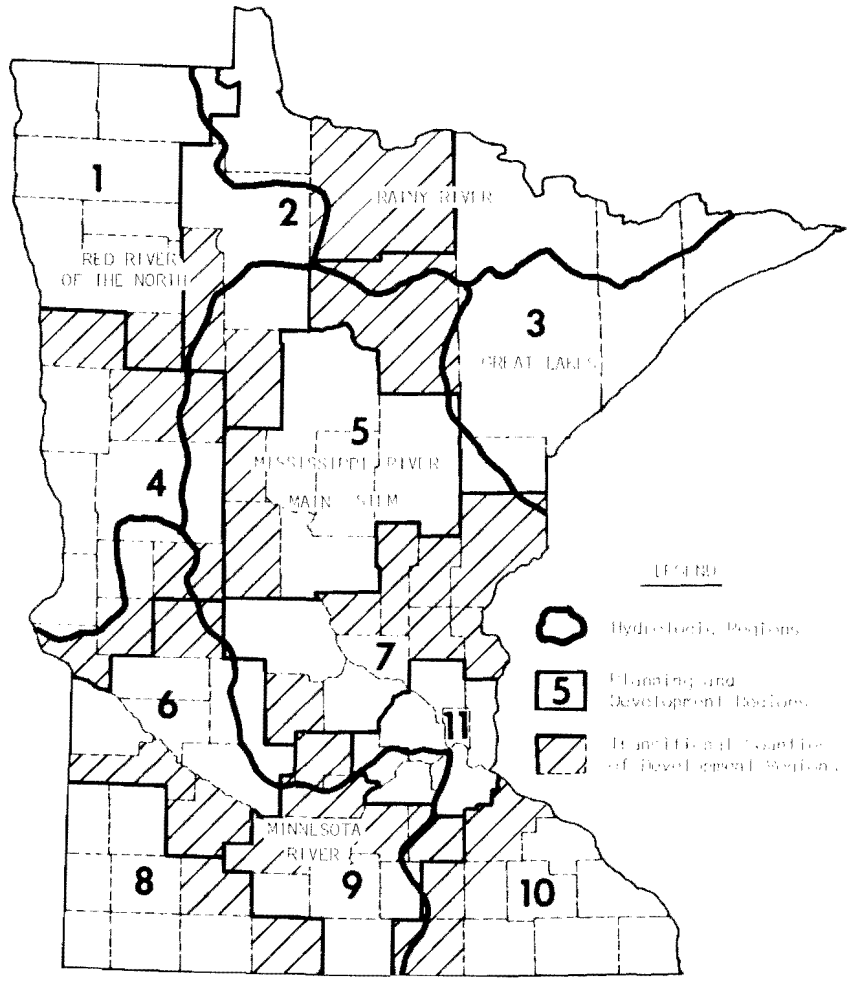

FIGURE 51. COMPARISON OF THE PLANNING AND DEVELOPMENT REGIONS WITH THE MAJOR HYDROLOGIC BASINS OF MINNESOTA

stages of project formulation, and being heard at hearings only sometime after original decisions are made and when their opinions are likely to cause little effective change. Further, such public participation as proposed would make regional management much more acceptable at local levels. This is desirable in view of the greater efficiency (critically needed) that can be achieved by regional management. Whereas the Governor customarily makes nearly all appointments to boards and committees, it is proposed that interest groups nominate panels of names from which the Governor shall make his selection. While maintaining the principle of executive selection, it gives interest groups the feeling of being represented by members of their choice.

All of the proposals also provide for the authorizing of State and/or regional agencies to own, construct, and operate facilities of all types including regional facilities. Local agencies will still be able to construct and operate their own facilities and make use of the resources within their boundaries but with the approval of the regional agencies and, where necessary, on contract to such agencies. Provisions for appeals, public hearings, arbitration and, ultimately, judicial court resolution are recommended for the handling of disputes.

The proposals are presented in a step-by-step development form in order to achieve greater clarity.

The integration of water quality management into water resources management can be achieved in essentially two ways. The first and perhaps the simplest is through the creation of a single regional agency with responsibility for all aspects of water resources management. The second would involve separate regional water quality management and water development agencies which can buy from, and sell services to each other and perform their functions in a fully coordinated manner. As Kneese and Bower (1) point out, this second alternative may be more difficult to administer but in the context of the United States of America where water quality and water development responsibilities are characteristically separated, it may be more practicable of attainment. Since quality and development responsibilities are separated in Minnesota, the first proposal, aimed at creating the least change from the status quo, should be based on the second alternative above, i.e. coordinated water quality and water development agencies.

Proposal No. 1

The existing agencies that immediately suggest themselves as the basis of this proposal are the Minnesota Pollution Control Agency (MPCA) in terms of quality management, and the Department of Conservation in terms of developmental activities. However, as pointed out in Chapter 4, both of these agencies are essentially regulatory in nature and deficient with respect to Craine's governmental involvement chart described in Chapter 2. Therefore, by legal authorization, financing, and improved staffing these agencies should be made capable of using the full range of alternatives and functioning fully, the one as a water quality management agency and the other as a water development agency. Most of the available alternatives and requirements to be met by agencies capable of functioning fully in these two areas have been discussed in Chapter 2.

The intelligence and planning activities of the MPCA should be upgraded so as to make a communications-control network for water quality management (see Chapter 2) a reality, perhaps first in the Mississippi River Basin. The MPCA should be authorized to use effluent charges as a means of controlling waste disposal into watercourses and perhaps assume the present authority of the Commissioner of Conservation for controlling water use by means of permits so that it can also charge water withdrawal rates and use them as a tool of water quality control. It is not absolutely necessary for the MPCA to issue the water withdrawal permits in order to introduce a water withdrawal charge since with the coordination planned for the operation of the two agencies (or their successors) it should be possible to operate the charges and the permits separately or possibly both by the Department of Conservation. Since effluent charges should, however, be administered by the quality management agency, it may be wise to have that agency administer withdrawal charges as well.

The two agencies should share responsibility for administration and execution of the comprehensive water resources plan now being developed by the State Planning Agency and also those plans being developed in cooperation with other States and the Federal Government. They should revise and update the comprehensive plan as necessary and be given authority to ensure that all water use and development in the State is compatible with that plan and meets with their approval, subject to appeals to their governing board to be described later, and to the courts of law.

Both agencies should be made capable of acquiring, constructing, operating, and maintaining structures and facilities relevant to their special interests of quality management and resource development, respectively. In this respect, the MPCA's powers would apply to waste treatment and disposal facilities while the Department of Conservations' would apply to dams, reservoirs, and other water storage and distribution facilities, and flood control works. These powers may be reserved mainly for use in the absence of the capability or desire of local and private agencies to build and operate needed facilities. The two agencies must also be authorized to build, operate and maintain regional facilities for water distribution and waste water disposal, and to require interconnections and sharing of common facilities among independent systems.

The MPCA's present responsibilities encompass the control of air pollution and solid waste disposal in addition to that of water pollution. In view of the *environmental interrelationships* earlier described, it is desirable to keep these three components of environmental pollution control together. Furthermore, it is proposed that the MPCA's responsibilities be expanded to include the control of all forms of land use which affect air and water quality. These responsibilities would include shoreland and flood plain management (now the Commissioner of Conservation's responsibility) and the control of agricultural, industrial and other land uses. This agency would thus be responsible for managing the quality of the State's natural resources (air, land and water) and should, therefore, be appropriately renamed. From here on it shall be referred to as the *Resources Quality Agency* (RQA).

In a parallel and complementary manner, the Department of Conservation would become the *Resources Development Agency* (RDA). It would

have responsibility for the developmental aspects of resources management. It would perform all the functions presently undertaken by the Department of Conservation (see Chapter 4) with the exception of those pertaining to shoreland and flood plain management which have been proposed for execution by the Resources Quality Agency. As mentioned earlier it may also be desirable to transfer responsibility for the issuance of water use permits to the RQA in order that that Agency may use both water withdrawal and effluent charges as water quality control techniques. In such a case, provision must be made through the Natural Resources Board (to be described later) to share the revenue from these charges between the RQA and the RDA. The development and management of State lands, parks and forests, and the propagation of fish and wildlife would be undertaken by the RDA.

The Resources Development Agency would cooperate with the Resources Quality Agency in the construction and operation of reservoirs and in-stream reaeration facilities, in the regulation of releases from reservoirs for quality control, and in the provision of other such services through a system of exchange payments. The RDA would similarly undertake developmental work pertaining to land use and air quality control for the RQA.

To ensure the coordination of activities of the two Agencies it is proposed that they function under the supervision of a single governing board called the *Natural Resources Board* and operate through jointly shared regional offices, staff and advisory committees as shown in Figure 52. There would be five regional divisions with the hydrologic-unit based jurisdictions selected in the previous section of the chapter. The Mississippi Main Stem River Basin Region could be operated from the head offices of the two Agencies in the Twin Cities, while the other regional operational centers could be sited at Moorhead in the Red River of the North Basin; International Falls in the Rainy River Basin; Duluth in the Great Lakes Basin; and Mankato in the Minnesota River Basin (see Figure 50).

The broadening of the arrangements to include the management of air and land resources poses a question as to the suitability of the chosen regions and regional centers for this broader purpose. On consideration of this question no strong reasons have been found that would make it incompatible to manage the State's air and land resources through the proposed regional system established on water resources considerations. Consultants (99) have recommended to the MPCA the organization of its Solid Waste Division on a district basis using offices established for the Water Quality Division. The Director of the Air Quality Division of the MPCA has also revealed that the regional centers of this proposal would be satisfactory for the management of the major airsheds being considered for use by this Division.

Natural Resources Board. The Natural Resources Board would have responsibility for establishing the broad policy under which the Agencies would operate, and also for their general supervision. It would serve as clearing house for the settlement of disputes between the Agencies and local and private agencies, groups, and individuals. This would ensure that the Agencies are executing their functions within the policy guide-lines of the Board and with due respect for the rights and wishes

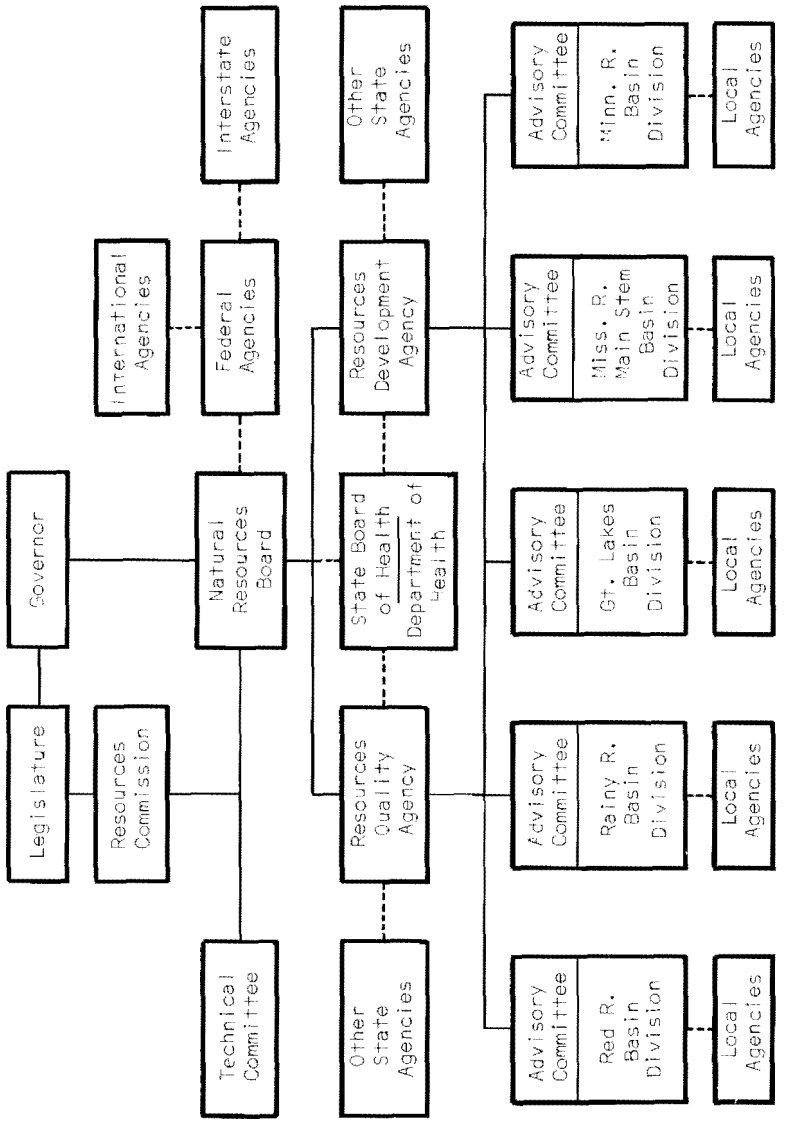

FIGURE 52. INSTITUTIONAL ARRANGEMENTS FOR WATER AND RELATED RESOURCES MANAGEMENT IN MINNESOTA, PROPOSAL NO. 1

of the public.

The Board, to be appointed by the Governor, should be as broadly representative of public interests as is possible without becoming unqieldly. It is proposed that one-third of the membership be made up of nominees of municipalities, counties, and the Regional Commissions to be set up under the Regional Development Act of 1969. Nominees of industry, agriculture and conservation groups should account for another third of the Board members. The final third should be made up of Governor selected citizen members and ex officio members from the Department of Health, the State Planning Agency, the State Geographical Board, the Historical Society, the Department of Agriculture, and the Geological Survey. The Chairman of the Board should be selected by the Governor from among his citizen appointments or ex officio members, and the Vice-chairman elected by the entire Board from among themselves.

The following, or some similar, formula may be used for selecting Board members. Municipalities and counties should be permitted one representative each for each of the five management regions for a total of ten members. These may or may not be members of the municipalities or council boards. The Regional Commissions should be allowed two members, making a total of twelve members from the first membership source. From the second source, industrial and agricultural interests, and conservation groups would then be allowed four members each to comprise another third of the total membership. To the six ex officio members, i.e., one each from the six State departments and organizations mentioned, the Governor would add six citizen appointments to complete the Board.

This plan would require that industrial, agricultural, and conservationist groups and associations be encouraged to form State-wide associations or assemblies (if these do not already exist) that would nominate panels of six persons from among whom the Governor would select four members each for Board membership. The reasoning behind this type of selection has already been explained.

Appointments to the Board, except for ex officio members, should be made for staggered four year terms with the terms of the Governor-appointed citizen members coinciding with that of the Governor.

A quorum may be set at 75 percent or possibly more than 50 percent of the membership with decisions being taken on a majority vote of members present, and the Chairman's casting vote if necessary. The Board should meet at least quarterly or oftener as members deem it necessary.

At thirty-six, the membership of the Board should not prove unqieldly. It would be large enough to permit its subdivision into committees and task forces for consideration of special issues. Composed as recommended above, the Board should have that balance of interests that would avoid domination by any single group, and which should instead foster the cooperation of group interests to the betterment of the State. In addition, it should give all concerned the feeling that their views are being heard effectively. Such a Board would obviate the necessity to organize ad hoc groups like the Advisory Plant Siting Task Force established by Northern States Power Company (NSP) in February 1970 to advise the Company on the

siting of future power plants and related matters. This 40-member Task Force is widely representative of private and governmental interests but is limited to a narrow purpose and lacks the permanency and continuity of the proposed Board. The Board would establish policy governing the operations of NSP and all other industries, as well as governmental and private agencies and individuals as they relate to the use of the State's natural resources and affect the quality of the environment.

The Board may be advised by a Technical Committee comprising the Executive Directors of its two Agencies - the Resources Quality Agency and the Resources Development Agency - the heads of the State Department of Health, the Geological Survey, and the Water Resources Research Center of the University of Minnesota; and the Natural Resources Director of the State Planning Agency. Other members may be coopted to the Committee as needed.

The Minnesota Resources Commission, created under the Omnibus Natural Resources and Recreation Act of 1963, Chapter 790 of the Minnesota Statutes, should provide liaison between the Board and the Legislature. The Board itself would provide necessary liaison between Federal, interstate, and international agencies and those under its jurisdiction.

Regional Advisory Committees. Under this proposal, a Regional Advisory Committee would be established in each of the suggested five river basin regions. These would be aimed at providing close liaison with local governments and various interest groups. County and municipal governments in each region should probably equally share 50 percent of the membership on these committees with the remainder being shared by local industry, agriculture, conservation groups, and the Regional Development Commissions. The Directors of the regional divisions of the Resources Quality Agency and the Resources Development Agency would be chairmen of the Committees and provide secretaries from their staff. Committee decisions, taken on majority votes, would become recommendations to the Natural Resources Board. These Committees should also be appointed to staggered four-year terms to provide continuity, and should meet at least quarterly.

Relations with existing State agencies. Resources management should be broadly based in view of the various aspects it encompasses. Public health considerations are very important but must be undertaken simultaneously with the need to protect plant and animal life, to prevent damage to property, to ensure optimal resource development and economic growth, and to maintain an acceptable and enjoyable environment. Hence the decision to place the control of air and water pollution, and solid waste disposal in the Resources Quality Agency rather than the traditional Department of Health which may be single-interest oriented.

The *State Board of Health* and the *Department of Health*, however, have very important contributions to make. The Interdepartmental Agreement between the MPCA and the Department of Health (see Department of Health, Chapter 4) provides an excellent basis on which the Department can make its contributions. This Agreement, or a similar one, should be made operable between the Department on one hand, and the proposed Natural Resources Board and its Agencies on the other. Similar formal agreements

may be made with other State agencies such as the *Geological Survey*, the *Department of Agriculture*, and the *University of Minnesota* for the provision of consultation, data collection, research and other services. Figure 52 indicates provision for such links among the Natural Resources Board, its Agencies, the State Board of Health and other State agencies.

Changes in current institutional arrangements. A number of changes in the current institutional arrangements are indicated as a part of this proposal. First of all the proposal makes the Water Resources Board redundant and it should be abolished. With it should go the Watershed Districts which it supervises and which have many weaknesses as pointed out in Chapter 4.

The Soil and Water Conservation Commission and the Soil Conservation Districts they supervise should be made to revert to their main original purpose and responsibilities pertaining to soil erosion control, and be shorn of their flood control, water pollution control and other water related activities.

Since the functions of the Metropolitan Sewer Board would be performed by the Agencies of the Natural Resources Board, then that Sewer Board should be abolished and all of its facilities, systems and financial obligations appropriately transferred to the Natural Resources Board and its Agencies. The Metropolitan Sewer Board was created mainly because of the absence of regional agencies of the type proposed. It was not originally intended that the Metropolitan Council should undertake developmental and operational activities. Its purpose was to coordinate the planning and development being done in the Metropolitan Area. Only in the sewage disposal area of its activities have such extensive developmental and operational activities been entrusted to the Council. Its functions through its Park Board and in the area of solid waste disposal are not as extensive as in the sewage disposal area and all of these functions would properly be undertaken by the Natural Resources Board and its Agencies. The Metropolitan Council would then function as originally intended.

All other special districts created with limited natural resources management objectives should be abolished in the interest of efficiency and reduction of complexity. These include sewer districts, pollution control districts, drainage and conservancy districts.

The activities of all local governmental units and agencies that pertain to matters falling under the jurisdiction of the Natural Resources Board and its two Agencies should be subject to the policies and regulations established by the Board and its Agencies. This change may be difficult to achieve but is a necessary one and should be attainable in view of the substantial local representation provided in the decision-making of the Board and its Agencies. Implementation of this change would place ultimate authority for matters pertaining to the natural resources of the State essentially in the hands of the Natural Resources Board and its Agencies and thus remove much of the existing confusion and consequent indecision and inaction. The decisions of the Board must, as stated earlier, be subject to litigation in courts of jurisdiction.

Comparison with the institutional criteria. The above proposal is seen to satisfy the first of the criteria developed in Chapter 3 with both Agencies being permitted to apply the total range of techniques through Stage 5 of Craine's schematic representation of governmental involvement.

By establishing regional management based on hydrologic units all under central control, the requirement of the second criterion for adjusting externalities stemming from hydrologic interdependencies can be met.

With the Natural Resources Board and the Regional Advisory Committees constituted as proposed, the Legislature should find no difficulty in giving the Agencies and the Board the necessary authority that would permit them freedom to set, revise and rescind their regulations, standards and permits as deemed necessary. Public hearings could be required prior to the issuance of orders and the increasing of rates by the Agencies in order to provide added stability. As already stated, the decisions of the Agencies would be subject to appeals to the Board and litigation in courts of jurisdiction. Provision may also be made for compulsory arbitration of disputes with local governments. It should, therefore, be possible to achieve the combination of flexibility and stability required by the third criterion.

The requirements of the fourth criterion pertaining to the ability to consider and express the full range of values are also satisfied by the proposal. The institutional system is such as to span the hydrologic demand and governmental systems; express and relate monetary and non-monetary values by pricing, exchange payments and interagency reviews; and satisfy the requirements for the representation of relevant interests, the adequacy of decision-making rules, and the provisions for hearings and appeals.

If, as proposed, withdrawal and effluent charges should be introduced, the Agencies should, with available State and Federal appropriations, have adequate financing. Ways should be explored to make instream recreational uses, which constitute a very important segment of the State's overall water use, contribute its proportional share of management costs. The Agencies should also be authorized to set rates and collect revenue for services provided and undertaken for municipalities and other governmental and private organizations, groups and individuals. With these sources of finance in addition to the authority to issue bonds, the Agencies should be financially viable thus satisfying the fifth criterion.

The sixth criterion pertaining to the extent to which management is built into government as a continuing function would also be satisfied by the proposal since all aspects of the institutional system including the Regional Advisory Committees would be given permanent legal status within the State's governmental system.

The provisions made for the coordination of the Resources Quality Agency and the Resources Development Agency should ensure the fullest possible satisfaction of the seventh criterion pertaining to the ability to account for environmental interrelationships. The two Agencies, it will be recalled, will have responsibilities for all forms of environmental quality management pertaining to water, air and land resources

as well as the development of those resources.

Proposal No. 2

Proposal No. 2 is identical to Proposal No. 1 in all respects except that the Resources Quality Agency and the Resources Development Agency would be combined into a single agency, perhaps called the *Department of Natural Resources*. This proposal would tend to eliminate any problems that may arise in trying to coordinate the activities of two agencies and have them share common regional staff. The first proposal would be of interest to the school of thought that would rather have pollution control and resources developmental activities in separate agencies.

Proposal No. 3

Proposal No. 3 differs from the two previous ones to the extent that responsibilities are divided between the central agencies and the regional ones on a horizontal rather than vertical basis. The central agencies would be essentially regulatory in nature performing mainly the functions now being undertaken by the *Minnesota Pollution Control Agency* and the *Department of Conservation*. Indeed these agencies could be retained but with their activities coordinated and supervised by a *Natural Resources Board* similar to that described in the first proposal. Alternatively, the agencies may be combined into a *Department of Natural Resources*. Since this is the level at which the policies of the State will be determined, and the regulations, standards and framework established within which the regional agencies will operate, it is felt necessary that the Natural Resources Board be retained with its broad membership as indicated under Proposal No. 1. The only change in the constitution of the Board should be such as to accommodate a member from each of the five regional agencies. The regional agencies would be independent *River Basin Authorities* each administered by a *River Basin Board* and fully authorized to function at Stage 5 of Craine's schematic representation of governmental involvement. The institutional framework of this proposal would, therefore, be as shown in Figure 53.

The *central agencies*, either separately or together as the Department of Natural Resources, would provide data collection, processing and reporting services to the River Basin Authorities. These central agencies would also have the responsibility of administering the execution of the Comprehensive Plan now being developed by the State Planning Agency. They would update and revise the plan and review all plans of the River Basin Authorities to ensure compatibility with the Comprehensive Plan. River Basin Authorities would be allowed to execute no plans without prior approval of the central agencies, subject to appeals to the Natural Resources Board and other channels as set out in Proposal No. 1. The central agencies would undertake research, the results of which would be made available to the River Basin Authorities. The central agencies would establish and enforce standards and regulations for the control of water quality, air pollution, solid wastes disposal and land-use management. Their responsibilities for controlling water use by permits should, however, be transferred or delegated to the River Authorities. Staffing and financing of these central agencies should be improved in order that they may perform the above functions, equivalent to Stage 3 of Craine's chart, fully and effectively.

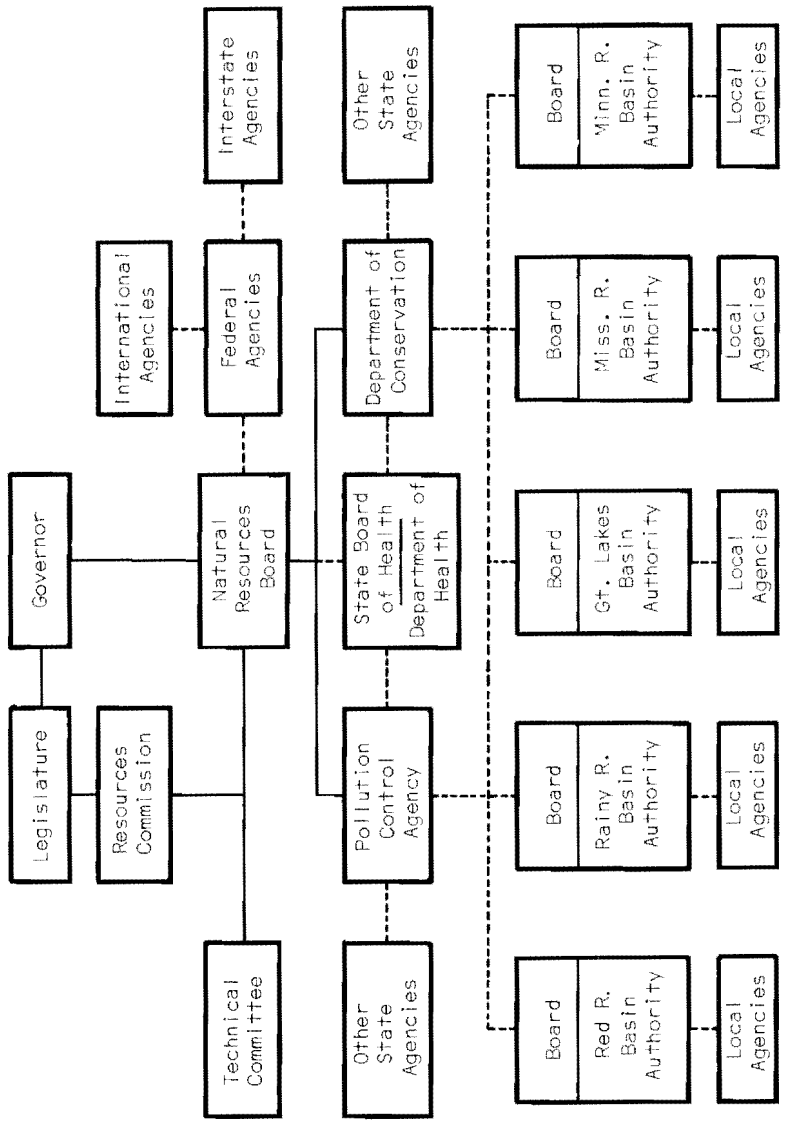

FIGURE 53. INSTITUTIONAL ARRANGEMENTS FOR WATER AND RELATED RESOURCES MANAGEMENT IN MINNESOTA, PROPOSAL NO. 3

The *River Basin Authorities* would be the executing agencies, initiating, planning, constructing and operating projects and facilities of both the quality management and developmental types. The areal jurisdictions would be the same as used in the other proposals and the Authorities would control all water use and development in those jurisdictions, and enforce the standards and regulations of the central agencies on behalf of those agencies. These Authorities would have similar powers to the Agencies of the previous proposals for setting rates and charges, and contracting for services with municipalities, and other local governmental and private organizations. In addition, the Authorities must be authorized to make water transfers with the approval of the central agencies and the Natural Resources Board, and also to make exchange payments among themselves.

The *River Basin Boards* to be responsible for administering the Authorities should be essentially local in nature and of similar constitution to that proposed for the Regional Advisory Committees of the previous proposals. The Chairmen should, however, be appointed by the Governor or elected by the members of each River Basin Board from among themselves. These Boards should also meet at least quarterly and possibly monthly. Each would be responsible for overseeing the day-to-day operations of the corresponding River Basin Authority whose Executive Director it would appoint.

This proposal, like the previous ones, would satisfy the institutional criteria developed in Chapter 3. Its main feature is that it permits the two main State agencies, the Minnesota Pollution Control Agency and the Department of Conservation, to continue functioning as regulatory agencies while leaving project execution to essentially locally controlled agencies. Whereas the previous proposals mainly involved the expansion and combination of existing agencies and their operation through regional district offices, this proposal involves the creation of five new regional water authorities. The recommendations made earlier concerning the existing Water Resources Board, State Soil and Water Conservation Commission, Metropolitan Council, special districts, and local governmental units apply as well to this proposal.

The proposals have been confined to ones that can be implemented entirely by the State of Minnesota without involving neighboring States. Provisions have been made through the Natural Resources Board for liaison with Federal, interstate and international agencies. In this way plans developed and decisions taken by Federal and interstate agencies can be given due consideration and be implemented by the proposed State agencies. With the Federal Government already coordinating the development and enforcement of water quality standards for interstate waters, and participating with States in developing comprehensive river basin development plans, the need to establish Federal-interstate compacts such as the Delaware River Basin Commission becomes increasingly less important. If, in addition, States provide water resources management meeting the requirements and the criteria developed in Chapters 2 and 3, then all that should be required at the interstate level would be river basin planning commissions that are permanent institutions with authority to prepare and update comprehensive plans for major river basin systems, coordinate Federal and State plans and recommend priorities. The River Basin Commissions being established under the Water Resources Planning Act of 1965, Public Law 89-80, seem to meet these conditions though it is probably still too early to determine whether they will function as intended. As earlier stated, Minnesota has been participating in the activities of two such commissions, the Souris-Red-Rainy River Basins Commission and the Great Lakes Basin Commission. The States of the Upper Mississippi and Missouri River Basins are yet to be organized into such basin commissions. The Upper Mississippi Comprehensive River Basin Study is being undertaken by an ad hoc coordinating committee while the Missouri River Basin Inter-Agency Committee, how chartered under the Federal Water Resources Council, is more permanent in nature with a standing committee in charge of its planning. Minnesota's policy should be to encourage the establishment of a basin commission of the first type for the Upper Mississippi River Basin and possibly also for the Missouri River Basin only a very small part of which is in Minnesota.

Comparison of Proposals

Proposals No. 1 and No. 2 provide the State with equally strong roles in the management of its natural resources. In both cases, the degree of State involvement is greater than that of Proposal No. 3 which provides mainly a policy setting, regulatory role for the State. Proposal No. 2, based on a single executing agency, should also be the simplest to administer. In view of its combination of a strong State role and administrative simplicity, Proposal No. 2 is the most favored and recommended one for implementation.

The reasons for favoring strong governmental involvement in water resources management have been discussed in Chapter 2. Most of them are equally relevant to the management of air and land resources. Management decisions and actions affect many local governmental jurisdictions and socio-economic systems. Also the need for efficient use and development of natural resources makes it imperative that very little be left to chance and that the management system be capable of considering and implementing the widest range of alternatives. Under these circumstances, States should intervene to the maximum possible extent without unnecessarily interfering with local initiative. Such intervention should extend to all levels of resources management, including regional development. Proposal No. 2 best satisfied this criterion in addition to the other recommended criteria.

III. POLICY MEASURES

The need for water quality management to play the role of the integrator of other aspects of water resources management has been stressed in Chapter 2. The policies of the State of Minnesota should be such that water quality management plays this role. With water withdrawals approaching the magnitude of the available resources in a number of areas in the State it is important that water quality management policies be such as to force efficient water use.

Economic incentives such as effluent and withdrawal charges are strongly recommended as means of achieving efficient water use. Research that would provide the basis for the introduction of such charges should be considered of high priority. Research should also be undertaken to

find appropriate ways of making navigation, recreation and other "in-stream" uses of water contribute their fair share of the expenses of water resources management and pay the price of other uses foregone in their interest. Howe and Bower (112) have pointed out that the use of water for navigation is not costless if other valuable uses must be foregone. As an example they refer to releases of storage water to maintain navigational depths when such water may instead be used for power, irrigation and improved water quality. Here in Minnesota, costly works have been undertaken to ensure adequate depths for navigation on the Mississippi and Minnesota Rivers with essentially no return contribution to management costs and at no cost to barge tow operators and other navigational users of the waterway. In addition, recreational uses have adversely influenced the operation of the Big Stone Lake flood control works for their primary purpose of releases needed for downstream water quality improvement from the reservoirs of the Mississippi headwaters. Since recreational uses of water and related land resources are of such significance in the State as described in Chapter 4, ways should be found of making them contribute their share of management costs. Efficient use of water requires that a price be placed upon all uses of the resource.

The inefficiency of fiscal measures as economic incentives to efficient water use has been discussed in Chapter 2. Less dependence should be placed on these tools. When used, they should be aimed at fostering the widest use of possible techniques and should apply to the cost of non-depreciable assets (land) as well as operation and maintenance costs.

Systems analysis should be used to the fullest extent as a tool of rational decision-making (see Chapter 2). Research to develop the necessary mathematical models of river systems, possibly starting with the Mississippi River, should be of high priority.

The State's ground-water resources should be managed as an integral part of its total water resources. To make this fully possible research is needed, among other things, to better establish the extent of the resources, the extent to which they are now being replenished, and the effects of urbanization upon the use and quality of these resources. It does not seem that the best use is being made of these resources particularly in the Twin Cities area where very large volumes of high quality ground water are discharged to waste after a "single-pass" use for air-conditioning. With its quality still essentially unchanged but for the added heat, this water is mixed with poorer quality waste waters discharged to surface courses. Policies should be adopted to force either the recycling of ground water used for air-conditioning, its subsequent use for other purposes or possibly its direct recharge to the aquifers. Alternatively, ground water may be restricted to uses requiring its high quality and alternative sources of low quality water used for air-conditioning and other cooling purposes. Possibilities should be explored of up-grading intermittent surface water run-off by storage in underground as well as surface reservoirs, and the joint management of those reservoirs to provide water releases when required. Such joint management would require the use of an approach based upon systems analysis.

CHAPTER 6

SUMMARY

In introducing the problem a case is made for integrating water quality management into total water resources management that is generally applicable to highly developed, densely populated areas. In such areas, population growth, urbanization, industrial and agricultural growth, and related factors have combined to increase water demands manifold in recent years. The resulting pressures upon relatively constant water resources have forced the repeated sequential use of water among cities, other communities and industries. Under these conditions, water quality becomes impaired and may limit water use. Furthermore, not only do the many competing water uses have conflicting quality requirements but their return waste waters also vary widely in quality and have widely varying effects upon the quality of receiving waters. Management must, therefore, be concerned not only with the quantitative aspects but simultaneously with the qualitative aspects of water resources if optimum use is to result.

I. WATER RESOURCES MANAGEMENT

Craine's (20) concept of *water resources management* as a governmental response to the growing need to maximize the productivity of hydrologic resources has been adopted in this study. This concept envisages water resources, with characteristics of quantity, quality, time and place, as the inputs to a water resources management system. The outputs from this system are the many uses (municipal, industrial, agricultural, etc.), environmental amenities, and economic development, all of which have characteristics of quantity, quality, time and place. Within the management system is a configuration of structural facilities and non-structural measures, and the institutions which provide and operate them.

Six characteristics of water resources are advanced as contributory factors to the need for public (governmental) involvement in water resources management. These are: (a) multiple use of the resources, (b) interdependencies in hydrologic systems, (c) regional disconformities, (d) scale economies, (e) natural monopoly and pricing, and (f) environmental interrelationships. The techniques available to governments for intervention are listed as water resources intelligence, identification of resources potentials and planning, regulation of water use, development of the water resources, and organization of regional water distribution and disposal systems. There is a progressional relationship among these five techniques which is depicted in Figure 2. The extent of involvement progresses from Stage 1 consisting only of the first technique, water resource intelligence, through Stage 5 in which use is made of all five techniques. The use of all five techniques is considered necessary for fully integrated water resources management, thus making governmental involvement at Stage 5 essential.

Water Quality Management

The concept of *water quality management* adopted is essentially that proposed by Kneese and Bower (1). It encompasses a whole range of acti-

vities from data collection, research and analysis through the use of various technical, engineering, and policy measures. Pollution control is but one constituent of water quality management. Technical and engineering measures for reducing waste generation, for reducing wastes after generation, and for making better use of the assimilative capacities of receiving waters have been described and discussed. The use of a communications-control network in the operation of a water quality management system based on a wide variety of these technical and engineering measures has been recommended.

Judicial, direct regulatory, and economic measures are the major groupings of policy measures discussed. The *judicial process* is seen as being incapable of yielding optimal water quality management. The use of an ombudsman to process complaints, the designation of special courts for handling water related problems, and the appointment of water management agencies as "masters in chancery" to aid courts in technical aspects of cases are among the recommendations for improving the role of the judicial process. The opinion is also expressed that the judicial process should play an essentially supplementary role to that of water management agencies, providing redress to those whose interests may have been inadequately considered by the agencies.

Direct regulation as a tool of water quality management is usually based upon a set of *water quality standards*. These standards are of two types: (a) *stream standards*, which establish quality requirements for receiving waters, and (b) *effluent standards*, which set requirements for wastes discharged into receiving waters. Stream standards, per se, are very difficult if not impossible to administer in situations where there are many waste dischargers. Under these conditions, stream and effluent standards must be used in complementary fashion. Effluent standards are typically of two types: (a) those limiting the strength and/or amount of particular waste substances, and (b) those requiring uniform waste treatment. While effluent standards are relatively simple to administer, they are shown to pose problems of efficiency and equity.

Effluent charges and *incentive payments* are the two main economic measures currently recommended as means of internalizing the externalities or spillover effects of one water user upon his downstream counterpart, and also for achieving efficient water use and quality management. Effluent charges, as proposed by Kneese and Bower (1), are based upon the principle that a charge per unit of waste discharged to a body of water would force the discharger to reduce his discharges to the point where the cost of an increment of waste reduction equals the effluent unit charge. To achieve optimum conditions, the effluent unit charge should be equal to the marginal or incremental cost of the damages that result from the waste discharge. If used to achieve a set of stream standards, then the effluent charge should be based upon the incremental cost of waste reduction at all relevant points of discharge in a river basin. While it is difficult to precisely determine damage costs resulting from specific waste discharges, Kneese and Bower (1) have proposed that effective effluent charges can be established using less precise evaluation techniques until better ones are available. The success of the effluent charges systems used by the management organizations of the Ruhr in West Germany, commonly known as the Genossenschaften, is an example of this.

Incentive payments made to waste dischargers at the same rates required for effluent charges have been shown by Kneese and Bower (1) to have the same result as effluent charges. Other economists such as Bramhall and Mills (57), Kamien, Schwartz, and Dolbear (58), and Freeman (59) have disputed this claim. In any case, Kneese and Bower have pointed to many administrative difficulties of operating a payment scheme and the fact that such a scheme would encourage unscrupulous operators to benefit by exaggerating their waste loads.

Fiscal incentives such as tax incentives, loans, and grants are generally considered difficult to justify on efficiency grounds. When used they should be aimed at fostering the widest possible range of techniques and should apply to the cost of non-depreciable assets (land) as well as operation and maintenance costs.

Of the policy measures discussed, only effluent charges and effluent standards can in theory produce economically efficient solutions, according to Kneese and Bower (1). These authors see no difference in the effect that effluent charges and effluent standards can have on resources allocation. What differences there are relate only to ease of administration, income distribution, and equity. These differences are as follows:

1. An effluent charge system requires less information regardless of whether the objective is minimization of costs associated with water quality management, or that of obtaining the least-cost system for achieving a stream standard.

2. Effluent charges offer incentive to maximum waste reduction while effluent standards provide none beyond the stream standard level.

3. Effluent charges exert continuous pressure on dischargers to improve their waste handling technology while a standards system only does this to the extent required to meet stream standards.

4. Effluent charges have the advantage of yielding revenue that may be used for financing regional collective facilities and water resources management generally.

5. Effluent charges, by making each discharger pay in proportion to the use he makes of the resource, are considered equitable. The application of the same effluent standard to all dischargers in spite of large differences in the cost of achieving that standard is considered of doubtful equity.

The Delaware Estuary Study (55; 60; 61) has shown that a system of effluent charges can achieve a given set of stream standards at less cost than a uniform-treatment type of effluent standards system. The Federal Water Pollution Control Administration concluded from that Study that the level of the effluent charges needed would be reasonable and unlikely to cause major economic adjustments. It is also pointed out that the administrative costs and management difficulties of the effluent charge method are not great enough to negate the advantages of the method. Support for the use of effluent charges as a tool of water quality management has been forthcoming from many other sources (62; 63; 64) and the State of

Wisconsin is currently studying its possible application (47).

Systems Analysis

The use and role of systems analysis in water resources management has been discussed. The growing complexity of water resource systems requires the development of means of rational decision-making if efficient resources use is to be achieved. What is termed systems analysis or operations research is finding increasing use as a means of providing the necessary basis of rational decision-making. *Systems analysis* is defined by Fisher (65) as being "concerned with the explicit description of the interactions between the various components of a complex situation, with precise statement of objectives sought, and with the prediction and evaluation of the consequences of taking various courses of action." A problem being analysed by this technique is usually stated in the form of a mathematical objective function that is to be optimized within one or more mathematical and/or qualitative constraints. Various techniques using both linear or static and dynamic or time-varying approaches have been developed and used in solving water resources problems. Systems analysis is a tool that should be available to all regional water resources management agencies.

Quality Management - the Integrator

Having considered the concept of water resources management and its constituent, water quality management, the thesis is advanced that water quality management should not merely be integrated into water resources management but should instead play the role of the integrator of the various aspects of water resources management. Water quality management should provide the nucleus that forces and induces overall water management policies and actions that result in the achievement of efficiency. The following reasons have been put forward in support of this thesis:

1. Water quality management is central to the provision of adequate water supplies.

2. Even in the presence of abundant water supplies, sequential use by cities and industries means that quality rather than quantity is likely to be the limiting factor. This position has been taken by the Committee on Water Resources Research, Federal Council for Science and Technology (14).

3. Proper quality management will force efficient water use through in-plant water recirculation and other similar measures.

4. In the regional approach to water resources management, the consideration of qualitative aspects will ensure full consideration of quantitative ones also. Where quantitative considerations are uppermost, however, downstream users may find their allocations reaching them but of quality completely unsuited to their needs.

The Mexican Treaty of 1945 which guaranteed Mexico 1.5 million acre-feet of water annually from the Colorado River is a case in point (24). The water reaching Mexico has been high in salinity and, as a result, damaging to Mexican crops.

5. It is, therefore, quality management that must be the limiting factor in determining the extent of governmental involvement in water resources management. Since water quality must be managed on a regional scale, governmental involvement is required at Stage 5 of Craine's chart described in Chapter 2.

6. Quality management will force the fullest consideration of the external or spillover effects of water use and lead to optimal resource allocation.

7. Likening water resources management to a jig-saw puzzle, the provision of comprehensive water quality management will, as it were, result in the other pieces of the puzzle falling into place.

II. INSTITUTIONAL ARRANGEMENTS

Criteria for Water Management Institutions

Based upon the major characteristics of water resources, earlier mentioned, the following seven criteria for water management institutions have been proposed. These criteria represent an expansion of Craine's set of six (20):

1. Ability to apply the total range of governmental techniques for influencing water use and development.
2. Ability to consider and adjust (or adapt to) externalities stemming from hydrologic interdependencies.
3. Flexibility to adapt water management actions to different circumstances of time and place with protection against arbitrary and capricious actions.
4. Ability to express and consider the range of values relevant to a water management decision.
5. Ability to finance water management consistent with its objective of efficiency.
6. The extent to which water management is recognized and built into government as a continuing function.
7. Ability to account for environmental interrelationships.

Roles of Governments of General Jurisdiction

The following roles have been recommended for the Federal, State, and local levels of government in water resources management:

Federal Government:

1. The establishment and maintenance of a clearly defined national policy on water resources management to serve as a guide and framework within which States may operate. This is in keeping with the Federal Government's responsibility for the welfare of the nation as a whole.

2. The provision of guidelines and incentives for States to establish and operate intrastate and interstate regional agencies with full authority to undertake water resources management as described in Chapter 2. The Federal Government may very usefully and effectively lead the

way to introducing some of the new techniques and concepts, such as effluent charges, that are important constituents of integrated water resources management.

3. The provision of supplementary funding of State and local management agencies to permit the fullest execution of all aspects of their programs, planning through construction and operation.

4. The joint undertaking with States of the preparation and periodic updating of comprehensive water development and management plans for all major river basins.

5. The expansion of its network monitoring stations of all types (quality, hydrologic, etc.) to provide basic background information against which to compare data from short-range stations. Such network monitoring stations may also be linked with those of regional agencies to provide information on which day-to-day management decisions can be made.

6. The provision of such other services, data collection and processing, periodic studies, and enforcement of regulations as cannot or are not undertaken by State agencies. Mediation services may also be provided for the settlement of disputes, particularly those with interstate repercussions.

7. The provision of joint representation with States on international commissions and for other activities pertaining to international boundary waters.

8. The maintenance of a strong program of basic and applied research, the results of which are made available to State and local agencies. Such a program should be coordinated with those of State and local agencies to ensure that each level of government and other agencies are undertaking the type of research to which they are best suited, and also to avoid unnecessary duplication. Advanced waste treatment, systems analysis, definition of water quality damage functions, analytical methods for water quality determination, and effects of synthetic and other chemicals on the aquatic environment are some of the areas requiring greater attention.

9. The expansion of its various training programs, courses, seminars, etc. to help States provide the increasing number of qualified staff members required for their programs. This would include increased financing of graduate students and research programs at universities.

State Governments:

1. Active promotion of the establishment of regional agencies of appropriate size and authority, and meeting the criteria proposed earlier in the chapter. Where interstate agencies are considered appropriate, States should work towards their early establishment, the same criteria being applicable.

Associated with this would be the reorganization of State agencies to reflect the abolishment and phasing out of departments, commissions, etc. made redundant by the establishment of regional water management agencies. The staffs, facilities, etc. of some of these existing State agencies should be used as the nuclei of the new regional agencies.

2. Provision of the broad policy within which the regional agencies will operate.

3. Establishment of clear lines of authority from State governments through regional agencies and local governments and agencies.

4. Promotion of the reorganization of local agencies in the interest of efficiency. This may involve the amalgamation and abolishment of existing agencies and the creation of new ones.

5. Provision of technical advice, services, and financial aid to regional agencies as required. This may include management programs in small areas on behalf of regional agencies.

Local Governments:

1. Active representation, not necessarily by elected members, on governing boards and councils of regional water management agencies to provide local input to decision making and liaison between regional agencies and local governments.

2. Management of their water supply, waste disposal, and other water-related facilities such as to meet the requirements of, and in close coordination with, the regional water management agencies.

3. Close coordination and integration of the activities of their agencies. In turn, the close coordination of these activities with those of the regional water management agencies.

4. The provision of water management services, at local levels, best handled by them on behalf of the regional water management agencies.

Institutional and Organizational Approaches

The institutional approaches to integrated water resources management used in four foreign countries and two regions of the United States have been described. These are the Genossenschaften of the Ruhr, West Germany; the River Authorities of England and Wales; the French Basin Agencies; the Ontario Water Resources Commission, Canada; the Delaware River Basin Commission; and the Wisconsin Department of Natural Resources.

Common to all of these approaches is the recognition that water quality management must be an integral part of water resources management; that some form of centralized control is necessary; that the approach must be a regional one involving river basins and hydrologic systems; that management agencies must in addition to their intelligence, planning and regulatory responsibilities be empowered to construct and operate facilities; and that ways must be found for getting meaningful local partici-

pation in decision-making. A variety of methods have been used in the various appraoches to achieve these ends.

The description of these approaches has emphasized the underlying concepts and principles upon which the approaches are based with a view to the possible application of some of these concepts and principles to the Minnesota situation.

III. WATER RESOURCES MANAGEMENT IN MINNESOTA

The water resources of Minnesota have been described with respect to their location, extent, quality, pollution, and use, and to the economy of the State. The existing institutional arrangements for their management have been critically examined with the following conclusions:

1. The water resources are relatively vast in comparison with those of most other States and more than adequate to meet present needs.

2. Population growth and the "burgeoning urban-industrial-agricultural economy" of the State are, however, placing rapidly increasing demands on these resources.

3. Concern has been expressed that problems will arise in many areas of the State - mainly the most populous and industrialized - as early as 1980 due to the full use of available quantities of water. Of even greater concern should be the fact that poor water quality has already limited and restricted many water uses in these areas and will further limit the use of available quantities of water in the absence of improved and adequate water quality management.

4. Water quality management is almost entirely limited to pollution control characterized by the use of effluent and stream standards to control waste discharges to waters. Absent are the wide variety of measures to improve the assimilative capacity of waters and the use of economic incentives to force optimum water use and the reduction of waste discharges.

5. Water quality management has not been playing the role it should in decision-making relative to the use of the State's water resources. Its role in water resources management should be a central one providing stimulus to optimal water (and related) resources use.

6. Water resources management in the State is characterized by a highly fragmented administrative system, the result of an ad hoc approach rather than truly planned growth. There are at least thirty major Federal, State and interstate governmental units contributing to water resources management in Minnesota and more than fifty others, governmental and private, with some degree of concern and involvement. Evidences of conflicts and unnecessary duplication are to be found together with jurisdictional confusion among agencies.

7. Water resources management in the State is significantly deficient with respect to all of the seven criteria for management institutions earlier proposed.

The extent of governmental involvement, particularly through State institutions, is essentially limited to resource intelligence, planning and regulation with very little activity of a developmental nature, or in regional distribution and disposal. Even with respect to those activities undertaken, the full range of alternatives available are not used. Until the very recent establishment of the State Planning Agency, and the Federal-State planning commissions and committees, truly comprehensive long-term planning has been absent. Data collection and particularly processing leave much to be desired. Much water use and water quality data collected by the major agencies are unprocessed and unavailable for use in day-to-day decision-making and even for long-term planning in many cases. Integrated water resources management (including water quality management) requires the functioning of governmental institutions through all stages of Craine's involvement chart described in Chapter 2.

The second criterion pertaining to the adjustment of externalities cannot be met under the present arrangements where responsibilities are fragmented among many agencies; where watershed units are so small as to be ineffective and in any case do not cover entire hydrologic units; and where there are no legal and administrative requirements for the exchange of payments among water use and development agencies in accordance with spillover damage or beneficial effects.

Departments are not always free to adapt their management decisions to different circumstances as required by the third criterion. The Legislature has from time to time passed laws restricting the Commissioner of Conservation's powers with respect to the issuance of permits for water extraction and use. Examples are the 1965 law the allowed the City of Cloquet to appropriate and use water from Lake Superior without the need for a permit; and the laws varying the permit system to allow more assured rights for water users in the mining industry than apply to other users. On the other hand, the Department of Conservation has seemingly arbitrarily limited appropriations for irrigation to six inches of water per acre per year; prohibited the assignment of water rights and transportation of appropriated water; and set limitations on what constitutes riparian lands. The important balance between flexibility and stability seems to be lacking. Furthermore the main source of public influence in management decisions is through hearings. Where there are policy making boards, in many cases they are not truly representative and are selected by politicians without affording interest groups and public sectors the opportunity to nominate their own representatives. While public hearings could be useful tools for determining public opinion they should not be used as a replacement for direct public access to decision-making boards and committees.

The ability to express and consider the range of values relevant to management decisions is severely limited by the jurisdictional fragmentation among agencies. Formal interagency review procedures are either non-existent or inadequate except for the Agreement between the Department of Health and the Minnesota Pollution Control Agency, and for the recent efforts of the State Planning Agency in bringing departmental heads together for long-term comprehensive planning. The weakness of public representation earlier mentioned also applies to this criterion.

There are weaknesses pertaining to decision making rules which have been discussed by Haik et. al (21) with respect to the operation of the water appropriation permit system by the Department of Conservation. This Department has no set of published rules, regulations or criteria for evaluating applications.

With respect to the criterion pertaining to the ability to finance water management consistent with the objective of efficiency, reference can be made to the limited activities of agencies such as the Department of Conservation and the Minnesota Pollution Control Agency stemming from inadequate financing. The latter agency had consultants recommend ways of improving its financing (101). Sources of revenue such as abstraction and effluent charges are not used and agencies must generally depend on legislative appropriations, grants and subsidies.

The sixth criterion is concerned with the extent to which water management is recognized and built into government as a continuing function. There is still the tendency towards ad hoc arrangements that do not lead to permanent legal and administrative measures. A relevant question is how permanent is the Water Resources Coordinating Committee and, stemming from this, what will happen to the comprehensive plan it is developing, upon the completion of the plan? What are the permanent arrangements being made to ensure the implementation of the plan and its continued updating? While it is possible that the Committee may be kept functioning indefinitely to revise the plan as needed, no agency is currently known to have the power to enforce its implementation.

The last criterion pertaining to the ability to account for environmental interrelationships has been receiving some recent recognition in the State. The replacing of the old Water Pollution Control Commission by the Minnesota Pollution Control (MPCA) with broader powers including the control of air pollution and solid waste disposal is an example of this recognition. The interrelationships will presumably be accounted for by handling within a single agency. The MPCA has also recognized that land use management is of importance and has commissioned a study by consultants (100). The Department of Conservation has also recently been preparing shoreland and flood plain zoning regulations which are likely to be fully operative within the next two years. The lack of, and need for, land use management that is relevant to water quality management (and water resources management) in the State has been very strongly attributed to by the findings of Borchert et. al (111) in their recent lakeshore study. Similar findings would no doubt result from similar studies of the State's other water resources.

IV. PROPOSALS FOR INTEGRATED WATER RESOURCES MANAGEMENT IN MINNESOTA

Three alternatives have been proposed for the achievement of integrated water resources management in Minnesota. An attempt has been made to fit the proposals not only to the physical characteristics and problems associated with the State's water resources but, importantly, to the prevailing governmental system.

The alternatives are not necessarily arranged in any order of preference but mainly in what is considered an ascending order of the magnitude of change from the present situation that would be required for their implementation.

Common to all the proposals is the increased public representation on the decision-making bodies of State and regional agencies. This would give the public, including local governments and special interest groups, direct input to the formulation and consideration of alternative action proposals, and really active participation in decision-making. It would answer the often expressed claim of the public of being excluded from the early stages of project formulation, and being heard at hearings only sometime after original decisions are made and when their opinions are likely to cause little effective change. Further, such public participation as proposed would make regional management much more acceptable at local levels. This is desirable in view of the greater efficiency (critically needed) that can be achieved by regional management. Whereas the Governor customarily makes nearly all appointments to boards and committees, it is proposed that interest groups nominate panels of names from which the Governor shall make his selections. While maintaining the principle of executive selection, it gives interest groups the feeling of being represented by members of their choice.

Regionalization

Regional decentralization is another of the common threads running through all of the proposals since this is considered a necessity. Hydrologically based regional units and the eleven planning and development regions established by Executive Order No. 37 of 1969 were considered in the light of the criteria earlier proposed. The use of the planning and development regions was rejected since these regions would considerably fragment the three major drainage areas of the State, viz., the Red-Rainy River Basins, the Great Lakes Basin, and the Mississippi River Basin, and make the management of the production functions of these basins and the accounting for spillover effects and hydrologic interdependencies very difficult to achieve. Five hydrologically based regions have been selected, viz., the Red River of the North River Basin; the Great Lakes Basin; the Mississippi Main Stem River Basin including the St. Croix River Basin; and the Minnesota River Basin together with the portions of the Missouri and Des Moines River Basins in Minnesota. These regions, shown in Figure 50, are considered small enough to bring the management agencies close enough to their problems while at the same time being sufficiently large to permit efficient management in accordance with the proposed criteria. Furthermore, the use of these regions would be in conformance with the policy of the Federal Government to foster regional river basin planning and development under the Water Resources Planning Act of 1965, Public Law 89-80, and also with the joint Federal-States comprehensive river basin planning now in progress under that Act,

It should be possible to successfully claim the "nonconformance" exemption under Section 6 of the Minnesota Regional Development Act for the use of the proposed hydrologically based management regions. The principles and spirit of the Act can be adequately met and promoted by the representation of the Regional Commissions to be established under the Act on the water and natural resources management boards and committees.

Proposal No. 1

This proposal envisages the joint management of the water resources of the State by a *Resources Quality Agency* and a *Resources Development Agency* (see Figure 52). The nucleus of the former agency would be the Minnesota Pollution Control Agency with the possible added responsibilities of the Department of Conservation for land-use management. The Department of Conservation would be the nucleus of the Resources Development Agency. Both of the new Agencies would be legally authorized and administratively organized to employ the full range of governmental techniques as required by the first criterion, i.e. they would be capable of constructing, operating, and maintaining structures and facilities of all types including those for regional collection and disposal of water and waste waters.

The two proposed State Agencies would be supervised and coordinated by a single *Natural Resources Board* appointed by the Governor and would operate through shared staff and facilities in five regional divisions with the river basin jurisdictions previously described. Attached to each regional division would be a *Regional Advisory Committee* made up of a wide variety of local interests including municipalities, county boards, and industrial, agricultural, and conservation groups. These Advisory Committees would provide liaison with local governments and interest groups. The Natural Resources Board would have similarly wide-interest representation to which would be added State-wide citizen members selected by the Governor, ex officio members of other State agencies and representatives of the Regional Development Commissions. A formula has been proposed that would result in such a widely representative board that isn't unwieldly or subject to group domination. The representatives of industry, agriculture and conservation groups would be selected by the Governor from panels of names submitted to him by these groups. The Natural Resources Board would have a *Technical Advisory Committee* comprised of the Executive Directors of its two Agencies and the heads of various other State departments or their representatives.

The *State Department of Health* would continue to provide its input to resources management by means of a formal interdepartmental agreement with the Natural Resources Board and its Agencies, identical with or similar to the existing one with the Minnesota Pollution Control Agency. This input would relate to the public health aspects of pollution of the environment. The Agreement would cover the provision of consultation, research, investigation, laboratory, and other technical and supportive services. The Department of Health would also continue to have prime responsibility, under the Agreement, for operations normally licensed by the Department, such as the provision of domestic water supplies, and the operation of domestic sewage disposal units. Such an arrangement underscores the major importance of public health considerations in resources management but also recognizes the importance of other considerations such as the protection of plant, animal life and property, the ensurance of optimal resource development and economic growth, and the maintenance of an acceptable and enjoyable environment. Similar agreements would provide other State departments, such as the Department of Agriculture, the University of Minnesota, and the Geological Survey, with means of input to the management process. Provision has also been made for liaison with

international, Federal, and interstate agencies through the Natural Resources Board. Liaison with the Legislature would be by way of the Resources Commission.

Proposal No. 2

This proposal only differs from the previous one to the extent that the two Agencies, viz., the Resources Quality Agency and the Resources Development Agency, would be combined into a single agency called the Department of Natural Resources. This would eliminate any problems that might arise in coordinating the activities of the two agencies of Proposal No. 1.

Proposal No. 3

This proposal (see Figure 53) differs from the two previous in that the responsibilities are divided between the central agencies (or combined agency) and the regional ones on a horizontal rather than vertical basis. The central agencies would be essentially regulatory in nature and, with the *Natural Resources Board*, set and administer State policies for the use and development of all natural resources. The *Minnesota Pollution Control Agency* and the *Department of Conservation* with few changes could function as the two central agencies, or combined as the *Department of Natural Resources*.

The executing agencies would be five *River Basin Authorities* each functioning under a *River Basin Board*. These Boards would have full controlling powers over the activities of the River Basin Authorities and not merely be advisory. The River Basin Boards and Authorities would have jurisdiction over all water use, development, and quality management activities within their regions while operating within the policy framework of the State Natural Resources Board and its agencies. The River Basin Boards would be similarly constituted to the Advisory Committees of the previous proposals. The only difference suggested is that these Boards be chaired by an appointee of the Governor or by one of the members elected by each Board from among themselves while the other proposals call for the Executive Directors of the Regional Divisions to chair the Advisory Committees.

Further details have been provided as to the functioning of all boards, committees, and agencies of the three proposals with respect to their decision-making rules and regulations, and review and appeal procedures that would ensure compliance with the proposed institutional criteria.

Associated with all of the proposals would be the abolishment of the existing Water Resources Board and the Watershed Districts they supervise. The Soil and Water Conservation Commission and the Districts they supervise would be shorn of their flood control, water pollution control and other water related responsibilities and limited to their original responsibilities pertaining to the control of soil erosion. The Metropolitan Sewer Board would be abolished and its facilities, systems and obligations transferred to the Agencies of the Natural Resources Board of Proposals No. 1 and No. 2, or to the River Basin Boards and Authorities

of Proposal No. 3. All other special districts such as sanitary, sewer, pollution control, and drainage and conservancy districts would be abolished. Finally, to avoid the existing jurisdictional confusion, the activities of all agencies, organizations, groups, etc. at all levels, State and local, pertaining to matters for which the Natural Resources Board and the proposed agencies have jurisdiction would be subject to the policies and regulations of that Board and its agencies.

No proposal has been made that requires the establishment of an interstate compact of any type. This is because it is felt that with the proper functioning of the River Basin Commissions being established with Federal and State participation under the Water Resources Planning Act of 1965, Public Law 89-80, the need for such compacts becomes increasingly less important. These Commissions have the necessary degree of permanency and the authority to do continuous comprehensive planning, coordinate the implementation of their plans, and also to suggest priorities. All that should be additionally required is adequate management within States.

Comparison of Proposals

Proposals No. 1 and No. 2 provide the State with equally strong roles in the management of its natural resources. In both cases, the degree of State involvement is greater than that of Proposal No. 3 which provides mainly a policy setting, regulatory role for the State. Proposal No. 2, based on a single executing agency, should also be the simplest to administer. In view of its combination of a strong State role and administrative simplicity, Proposal No. 2 is the most favored and recommended one for implementation.

The reasons for favoring strong governmental involvement in water resources management have been discussed in Chapter 2. Most of them are equally relevant to the management of air and land resources. Management decisions and actions affect many local governmental jurisdictions and socio-economic systems. Also the need for efficient use and development of natural resources makes it imperative that very little be left to chance and that the management system be capable of considering and implementing the widest range of alternatives. Under these circumstances, States should intervene to the maximum possible extent without unnecessarily interfering with local initiative. Such intervention should extend to all levels of resources management, including regional development. Proposal No. 2 best satisfies this criterion in addition to the other recommended criteria.

Policy Measures

As earlier stated water quality management should play a central integrating role in the management of the State's water resources. Management institutions should be capable of using the full range of policy measures proposed for the management of water quality in order to force efficient water use. It is very important that this recommendation be adopted in view of the fact that water withdrawals for various uses are approaching the magnitude of the available resources in many area.

Economic incentives to efficient water use such as effluent charges and withdrawal charges should be introduced. Ways should also be found to make navigation, recreation and other in-stream uses of water that benefit from the management of the resources contribute proportionately to the cost of that management. Less reliance should be placed on the use of fiscal incentives which cannot be justified on grounds of efficiency.

Systems analysis should be used to the fullest extent as a tool of rational decision-making.

The State's ground-water resources should be managed as an integral part of the total water resources. Ground water and surface water should complement one another, each being put to uses for which it is best suited. Ground-water reservoirs, where suitable, should be used to store and improve the quality of intermittent surface water runoff and make such water available in drier months.

Research Needs

Research should be undertaken:

1. To update and streamline all laws within the State pertaining to water and related resources management and also with a view to making legal terminology and definitions more closely reflect the advances in scientific knowledge.

2. To provide the basic information necessary for the implementation of systems of charges for water withdrawals from, and effluent discharges to, bodies of water and also for in-stream water uses.

3. To better establish the extent of the ground-water resources, the hydraulic characteristics of these resources, and the effects of urbanization upon the use, conservation, and quality of these resources. This is necessary to facilitate the recommended integrated management of ground and surface water resources.

4. To provide the necessary data for the development of mathematical models of the major streams and the use of the recommended communications-control networks for water quality management. In this respect the Mississippi River Basin should receive top priority.

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