STATE OF DELAWARE

DELAWARE GEOLOGICAL SURVEY

SPECIAL REPORT

LONG-RANGE PLAN FOR WATER RESOURCES INVESTIGATIONS IN DELAWARE

Newark, Delaware
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CONTENTS

ILLUSTRATIONS

INTRODUCTION

In 1959 the State of Delaware published a report entitled "INTRASTATE WATER RESOURCES SURVEY." In this report estimates of population growth and water requirements for the next several decades are presented. Projections of population growth indicate that Delaware will have 631,000 people in 1965, 857,000 in 1980, 1,426,000 in 2010, and 3,352,000 in the year 2060. (See figure 3). It is obvious that such a population increase would have a tremendous effect on water utilization. The report on the INTRASTATE SURVEY suggests that total water use by the year 2010, except that for industrial cooling and steam generation, will be about 1,300 mgd (million gallons per day).

These figures may appear very high to us at present, but the Corps of Engineers, U. S. Army, estimates that the greater Wilmington area alone will require 567 mgd by the year 2010. It is also quite clear that a great deal of economic development will take place in Kent and Sussex Counties, particularly along the coast of Delaware Bay which has excellent industrial sites, and along the ocean beach with its good recreational opportunities. In addition, irrigation which increased eight-fold between 1956 and 1960, is expected to demand very significant quantities of water in the years to come, particularly in times of drought when the water table is low.

On the basis of these considerations we must draw the conclusion that optimum development of our water resources will become imperative. Such optimum development can only be based on detailed knowledge of our water resources. We need adequate information with regard to stream flow, the occurrence, depth, thickness and areal extent of ground-water reservoirs, the quality of water they contain, and the dangers of salt-water encroachment. Also we need to experiment with methods of increasing local ground-water withdrawals by artificial recharge and by induced infiltration from impounded streams or lakes.

In order to obtain sufficient data which will enable the State to develop its water resources to the fullest extent of which they are capable, a series of systematic investigations is necessary. A long-range plan describing these studies is the subject of this report. A brief discussion of water in Delaware is presented first to provide a proper background for the long-range plan. The plan itself merely outlines the overall objectives and types of investigational work that must be pursued if the State is to develop its water resources wisely. This is followed by concluding statements which emphasize the need for early action. Appended to this report are pertinent reference data, including a list of proposed projects in order of their priority and a bibliography of available reports on Delaware's water resources.

WATER IN DELAWARE

DISTRIBUTION OF SUPPLIES

The distribution of water supplies in Delaware is controlled chiefly by local topographic and geologic features. As the State embraces part of two physiographic provinces, the Piedmont and Coastal Plain (figure 1), there is a marked difference in the availability of water in these two areas.

The Piedmont province lies north of a line between Wilmington and Newark, Del. and comprises about 6 percent of the land area of the State. The topography in this section of the State is fairly rugged and, therefore, is suitable for the construction of dams and storage reservoirs for the optimum development of surface-water supplies. However, conditions are not so favorable for the development of ground-water supplies because the subsurface formations are composed of relatively dense and impermeable crystalline rocks. These rocks yield only small supplies of ground water from fractures and fissures in the zone of rock weathering near the land surface. For the most part the supply available is adequate for domestic purposes but inadequate for industrial and municipal needs.

The major part of Delaware lies within the Coastal Plain province. The flat topography characteristic of the area does not provide suitable sites for major surface reservoirs. Nevertheless, small barrier dams and excavated ponds can be constructed to provide for irrigation and other farm uses. The use of barrier dams on tidal streams may prove beneficial to the quality of water available in the area by preventing brackish water from moving upstream in response to tidal impulses.

Although large surface-water developments are impractical, the Coastal Plain portion of Delaware is blessed with considerable ground-water supplies. The subsurface formations are composed of alternating beds of sand, gravel, and clay. These sediments, particularly the deposits of sand and gravel, are many times more porous and permeable than the crystalline rocks. The permeable beds, called aquifers, form extensive underground reservoirs for the storage and movement of large quantities of water. Modern wells tapping these underground reservoirs are capable of yielding as much as 1100 gallons per minute for long periods of time. The average yield of high-capacity wells in the Coastal Plain however, is about 350 gpm, much less than the figure quoted above. The location and extent of the principal aquifers serving the water needs of Delaware is shown on figure 2.

PRESENT USE

The use of water in Delaware has steadily increased since the first white settlers arrived in the State in 1631. Although no complete records are available concerning the use of water in the State prior to the first State-wide inventory made in 1954, the previous trend in water utilization

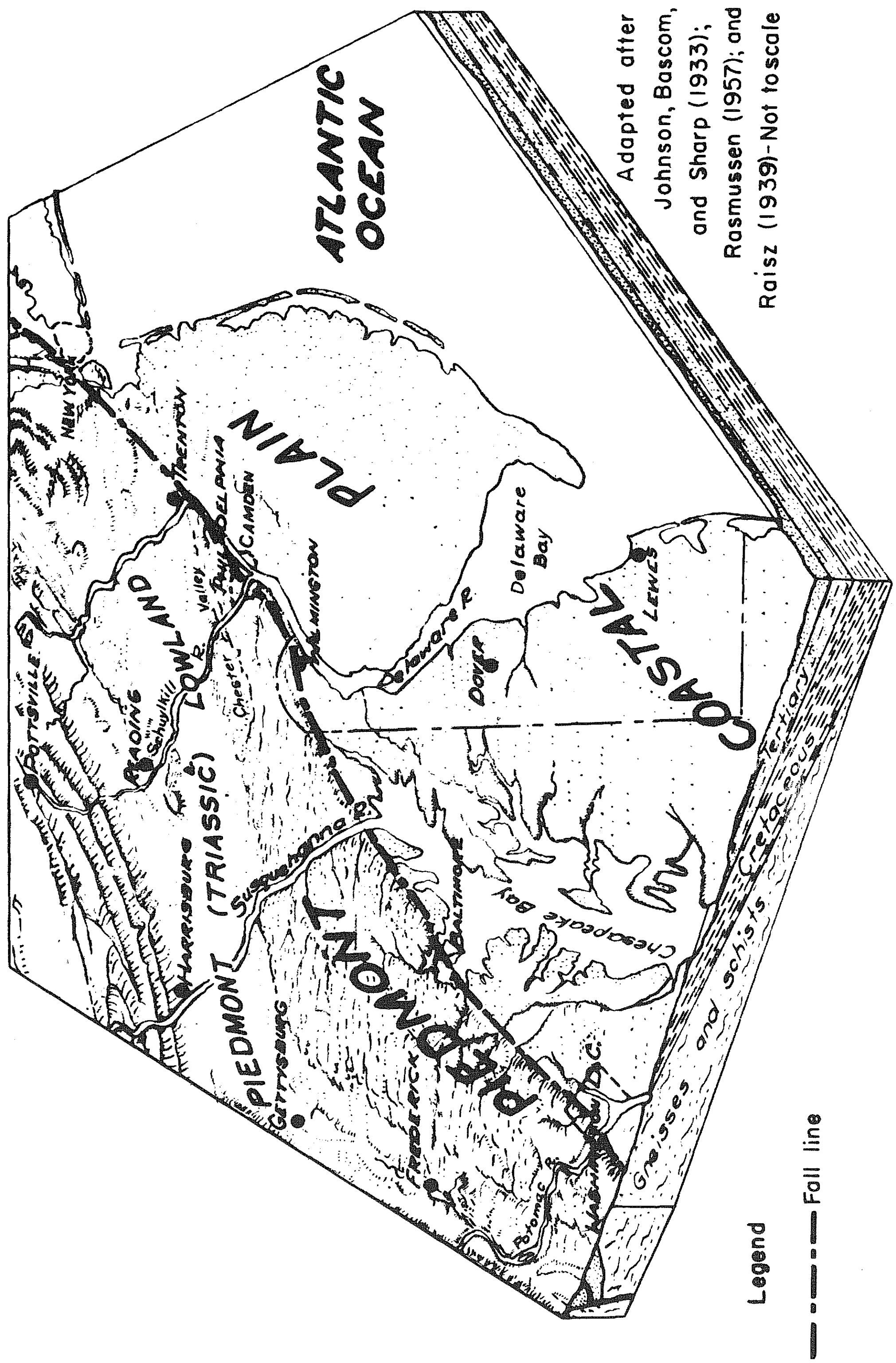

Figure 1. - Physiography of Delaware.

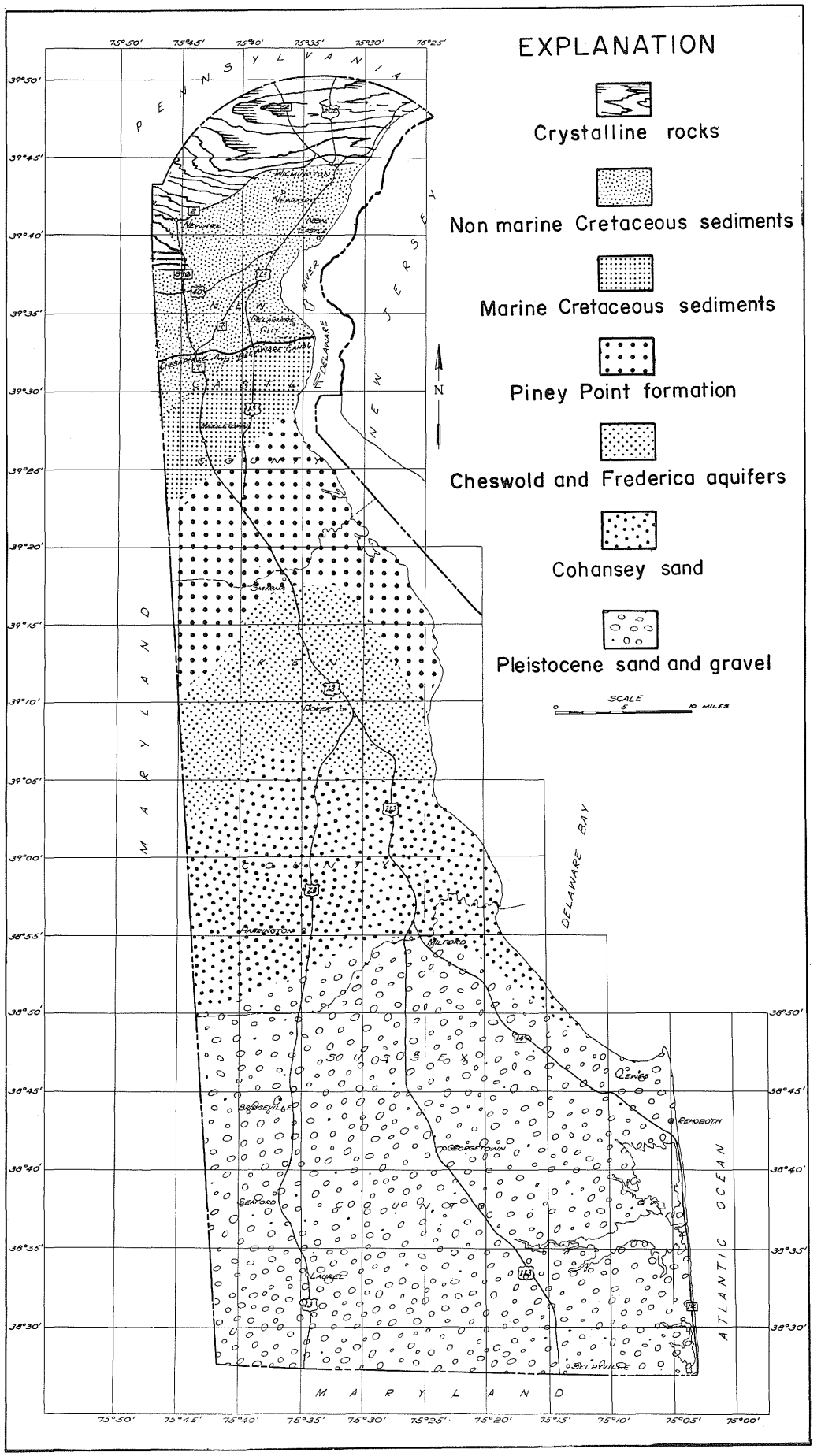

Figure 2. - Principal sources of ground water in Delaware.

is indicated by the graph in figure 3 showing the past and future population growth in Delaware from 1790 to 2060. Owing to the increase in per capita use of water, the actual trend of water use probably increased at an even greater rate than did the total population.

In 1960 the average daily use of water in Delaware for all purposes except the generation of power was about 115 mgd or about 260 gallons per day per person. The breakdown of this figure in terms of source and type of use is given in the following table:

Type of use	Source		Total
	Surface mgd	Ground mgd	mgd
Industrial	27.8	26.5	54.3
Municipal	28.5	16.5	45.0
Rural	0	11.5	11.5
Irrigation*	2.1	1.9	4.0
Total	58.4	56.4	114.8

*This figure is based on a 365-day year for purposes of comparison.

It should be noted that during the summer months 3 to 4 times the daily average may be required to satisfy peak demands.

The use of surface water is confined almost entirely to the northern or Piedmont section of the State. In fact, practically all the water is diverted from four streams in northern New Castle County, namely, Brandywine Creek, White Clay Creek, Red Clay Creek, and the Christina River. The average daily discharge of these and other streams in Delaware for which records are available is shown in figure 4.

In contrast with the use of surface water, the use of ground water is fairly evenly distributed throughout the Coastal Plain section of the State. The relative magnitude and distribution of the principal centers of pumping are shown on figure 5. In addition, the type of use, whether municipal, industrial, or rural is illustrated by means of a pie diagram for each of the three counties. It should be noted, however, that the rural use of water as shown does not include water used for irrigation.

Additional quantities of water can and, no doubt will, be developed from surface and underground sources in Delaware. However, considerable geologic and hydrologic study will be required to develop this valuable resource efficiently and economically to serve the future needs of the State.

FUTURE NEEDS

Population projections for Delaware (fig. 3) indicate that the population will approximately triple in the next 50 years and increase about 7 times

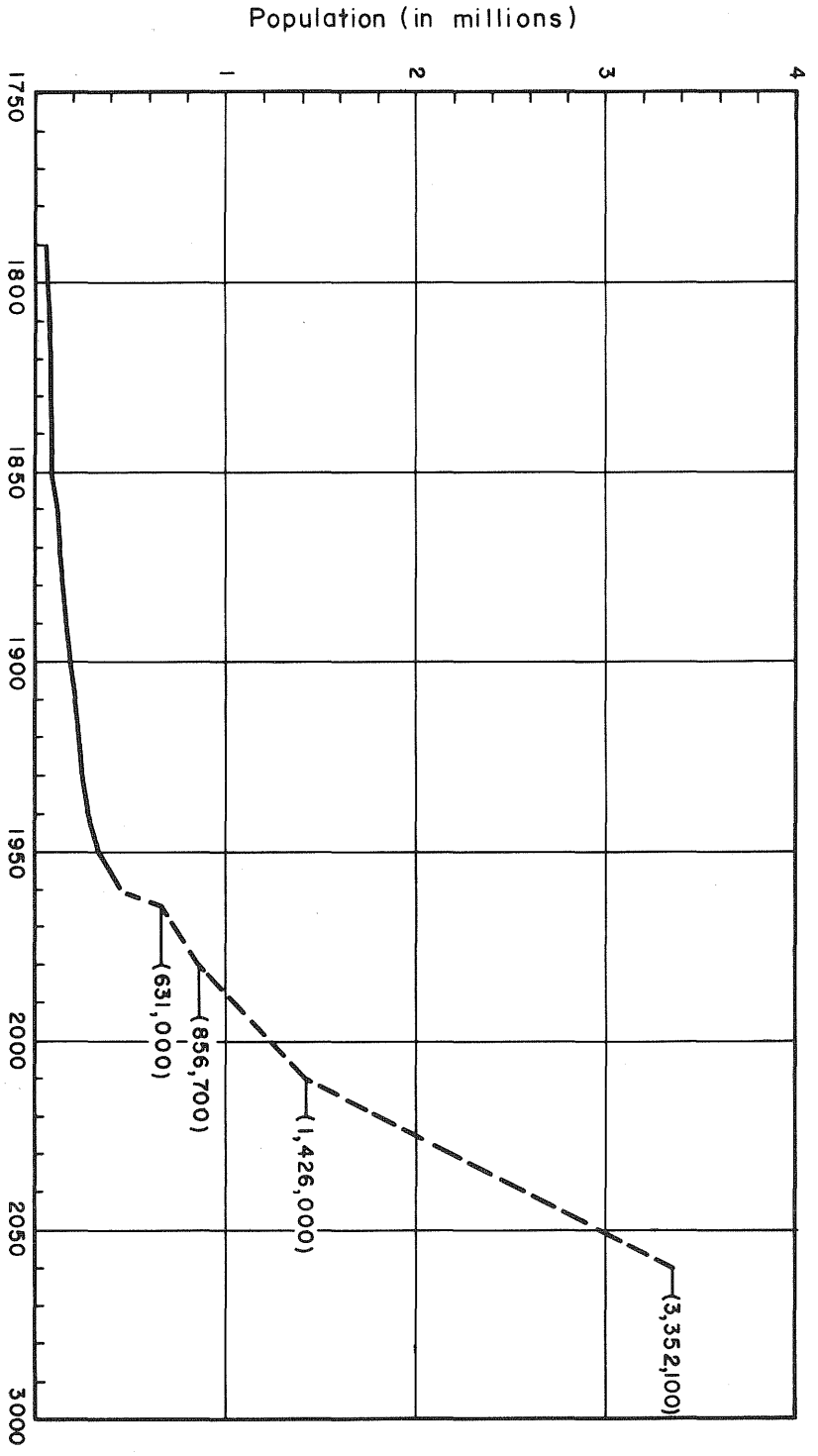

Figure 3. - Population growth and projection in Delaware, 1790-2060.

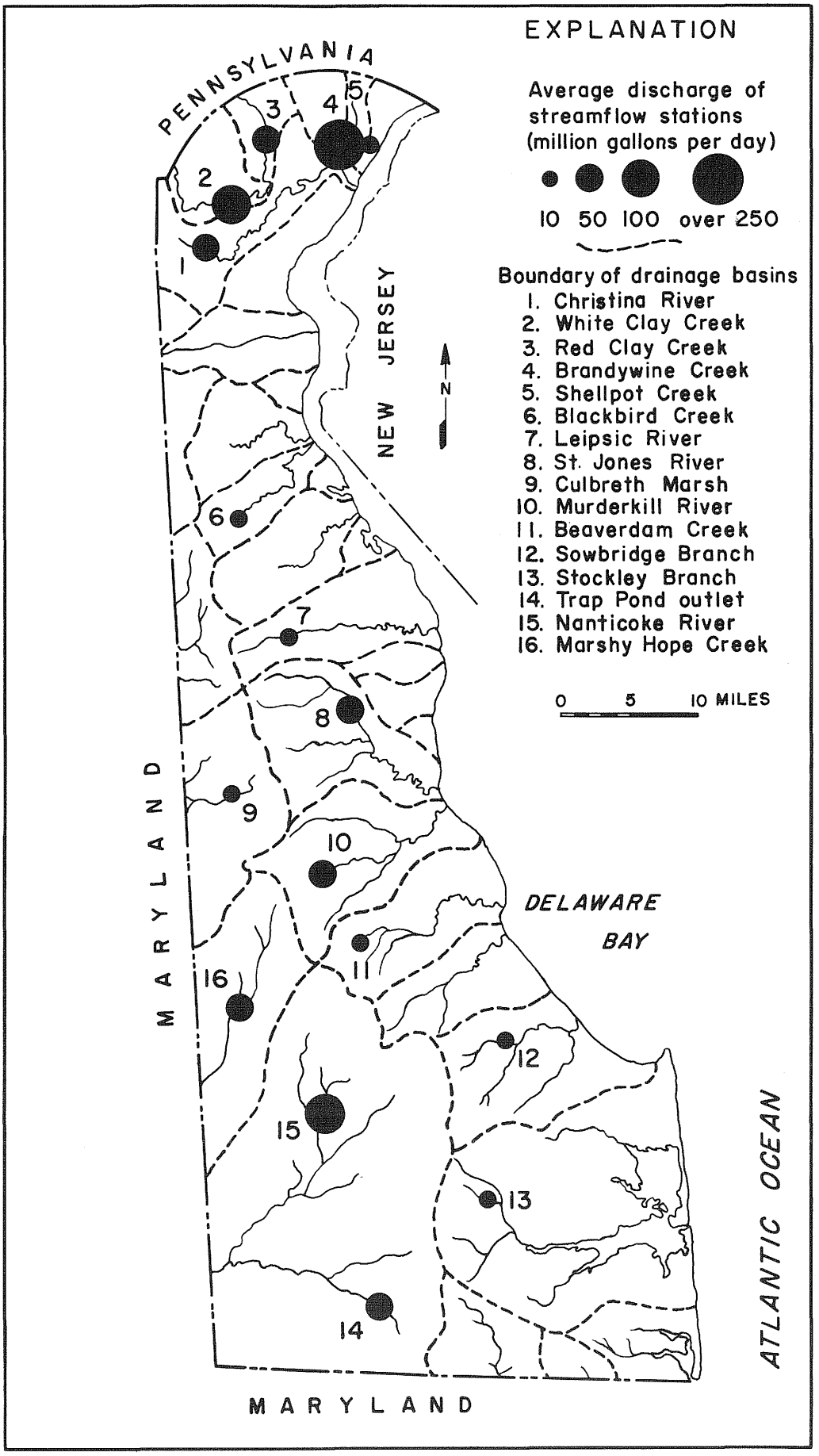

Figure 4. - Average daily streamflow at gaging stations in Delaware.

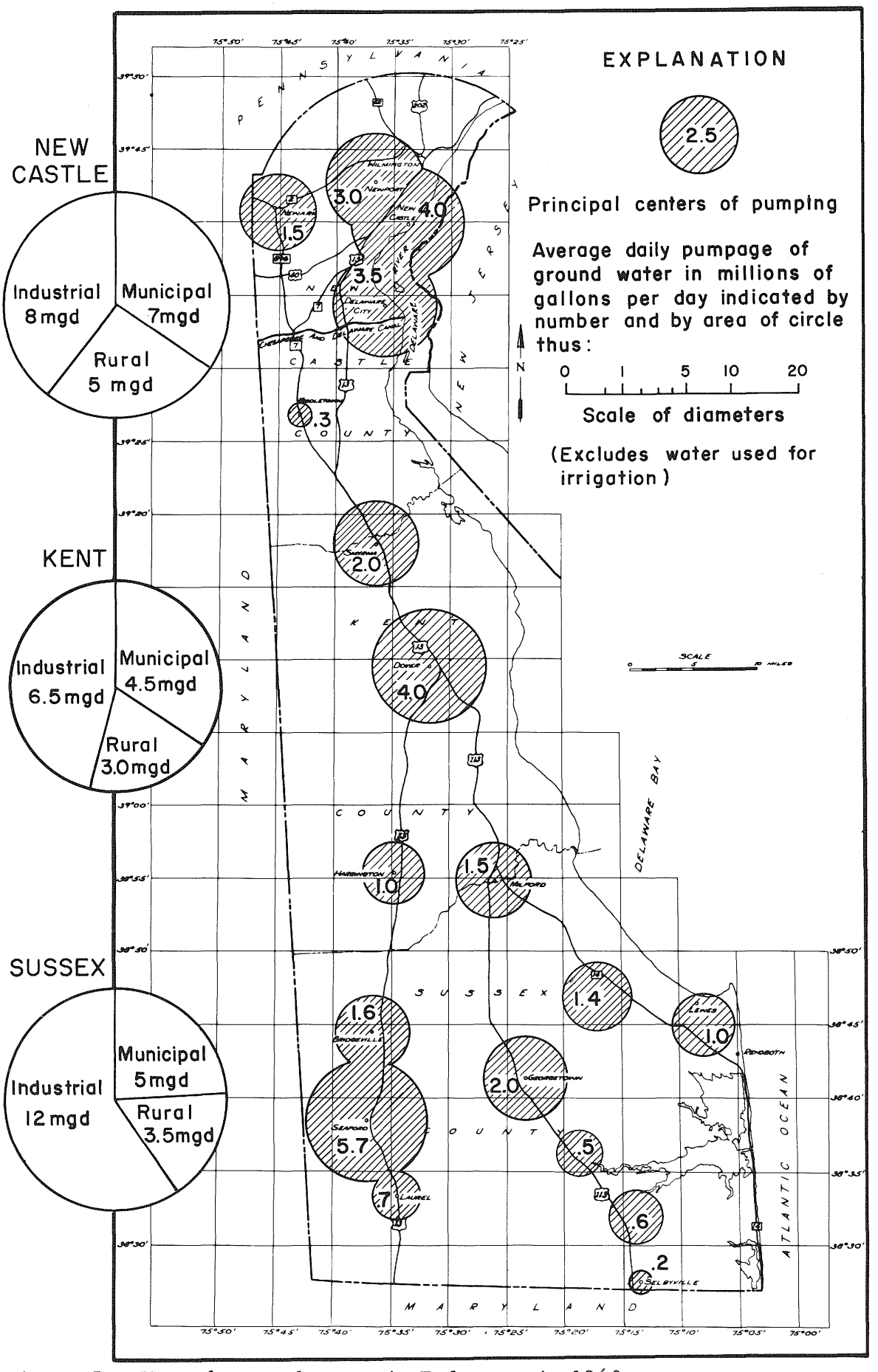

Figure 5. - Use of ground water in Delaware in 1960.

in the next 100 years. Industrial expansion can be expected to take place at a comparable rate. In addition, the per capita use of water is sure to increase appreciably as evidenced by past records and present trends. On the basis of these projections, the INTRASTATE WATER RESOURCES SURVEY reports that the average daily use of water in Delaware will increase to approximately 1300 mgd by the year 2010. This is slightly more than ten times the volume of water used in 1960. The INTRASTATE SURVEY also suggests that in the succeeding fifty-year period (2010-2060) the State's water needs will probably double or perhaps even triple. Even if these projections are considered to be rough approximations, they clearly indicate the necessity of planning for the maximum development of Delaware's water supplies to keep pace with the expanding economy.

PROBLEMS

In Delaware as well as in other eastern States, there has been a tendency toward complacency when considering future water supplies. As previously indicated, studies of past development, population growth, and increased use of water show clearly that such complacency is unjustified. Although large quantities of water are available in the streams and underground reservoirs, the supply is unevenly distributed with respect to time and location. As a result, numerous problems arise when attempts are made to obtain the right quantity of water at the right place, at the right time to satisfy specific needs. These problems are generally local in nature, but they tend to cripple development throughout the State, and thus prevent the orderly exploitation of the supplies available.

Development

In many parts of the State development of water supplies has needlessly been curtailed owing to inadequate knowledge of local hydrologic conditions. For example, the City of Newark has, for many years, imported water at a relatively high cost to satisfy part of its needs because several attempts to obtain additional local supplies were unsuccessful. Recent investigation has revealed the presence of an adequate supply of ground water within a few miles of the City that will more than double its present supply. Similar "water shortages" have needlessly curtailed development of water supplies in other areas where supplies could have been located if adequate water information had been made available. These problems can be avoided if systematic investigations precede development.

Overdevelopment

As more and more water supplies are developed in Delaware to keep pace with the expanding economy, overdevelopment of the supply is to be expected, chiefly in areas of concentrated water demand. There are indications that overdevelopment has already occurred in some parts of Delaware, namely in the highly industrialized areas of northern New Castle

County and in parts of Kent County. In these areas, signs that localized use of ground water may be approaching or exceeding the quantity of water available, are indicated by continuing water-level declines. Ordinarily, in the development of ground-water supplies, declines in water levels are necessary and need not be a cause for concern unless the reasons for the declines cannot be explained. However, where large amounts of water are being withdrawn from a group of closely spaced wells, the total pumpage may be excessive causing water levels to decline year after year. Inevitably this leads to competition for the available supply, to the ultimate detriment of all users.

Contamination

Equally alarming, and perhaps more serious, are the problems of impairment of water supplies by contamination or pollution. Contamination of water supplies in Delaware stems from two main sources -- disposal of municipal and industrial wastes, and encroachment of saline water into fresh-water aquifers.

Municipal and industrial wastes

As industries and communities develop, wastes are discharged into streams, or spread on the ground, or disposed of in cesspools or drainage wells. In addition, city dumps and sanitary land-fills swell in size and number. Eventually these wastes contribute substantial quantities of soluble materials to both surface and ground-water reservoirs. When water thus polluted is withdrawn from wells and streams, significant and often deleterious changes occur in the chemical character of the water.

Few communities are spared from this insidious threat to their otherwise dependable water supply. Moreover, the threat of pollution will increase in the future as industries and communities continue to grow. The protection of water supplies will, therefore, become increasingly important. Although little can be done to overcome the damage that has already been done, a consistent effort should be made to decrease the incidence of pollution in the future by publicizing the effects on the local hydrologic regimen of undesirable waste disposal practices.

Saline-water encroachment

The possible encroachment of saline water into fresh-water aquifers poses additional problems of contamination. Areas where this may occur are shown in figure 6. Under natural conditions, saline-water encroachment does not occur because the fresh-water head is sufficient to cause fresh water to flow out of the aquifer into the body of saline water. However, when wells are installed and pumped adjacent to bodies of saline water, the fresh-water head is reduced, permitting the encroachment of saline water into the aquifer.

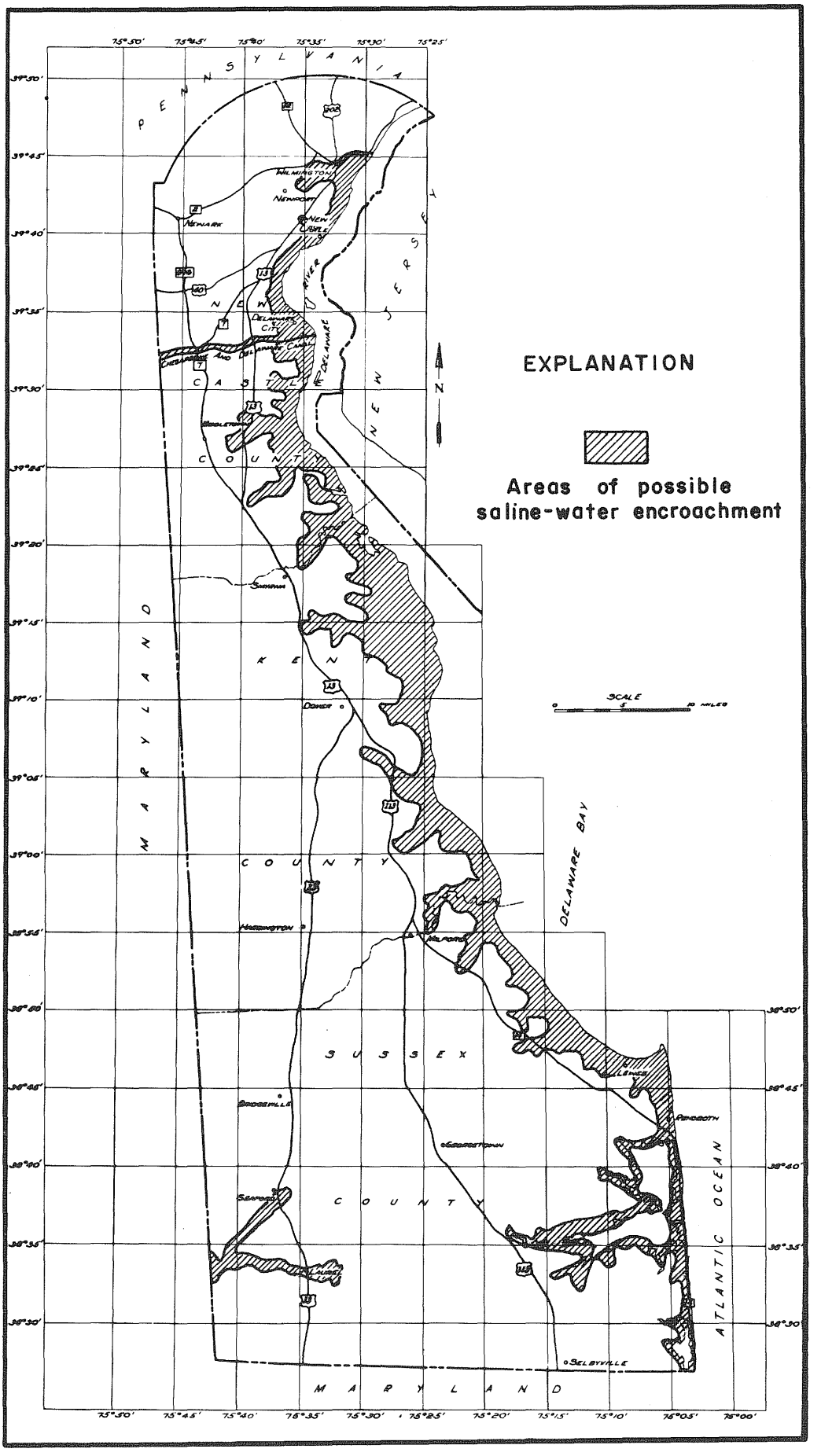

Figure 6. - Areas exposed to saline-water encroachment.

Previous studies along the eastern shore of Sussex County indicate that substantial parts of the shallow Pleistocene aquifer have been invaded by saline water. Well fields in the Lewes-Rehoboth Beach area have been abandoned owing to an intolerable increase in the chloride content, and new wells have been constructed some distance inland. This cannot be considered as a permanent cure because there is no assurance that the encroachment of saline water has been arrested. Without such assurance the future of the water supplies in the Lewes-Rehoboth Beach area remains in jeopardy.

Information relative to the nature and extent of salt-water encroachment is scant. In view of the consequences, this problem deserves prompt attention. Investigations should be made of actual and potential areas of salt-water intrusion with a view to their amelioration or control.

Water conflicts

Additional problems are created by conflicts over the use of water. These are inevitable because various uses of water are of necessity competitive. For example, a surface reservoir constructed for water supply is not always useful for flood control; streams used for water supply, recreation, or to support marine life cannot be used for waste disposal without extensive and often expensive treatment of the wastes. Excess pumping of ground water may lower water tables and unduly increase pumping costs, or may induce encroachment of saline water into fresh-water aquifers. Development in river basins may constrict flood channels and create flood problems. Flood plain zoning is necessary to limit infringement on the capacity of stream channels. Use of water for irrigation has greatly increased in the last decade. This use is in strong competition with other water use as it depletes the supply when flow in streams and storage in ground-water reservoirs are approaching minimums.

SCOPE AND LIMITATIONS OF EXISTING INFORMATION

Prior to 1943 the water resources of Delaware received scant attention. For the most part, published information on the subject was restricted to brief comments that appeared in reports on adjacent States and in reports covering regions of which Delaware is a part. Within the State, investigations were limited to periodic appraisals of the source and quality of public water supplies by the State Health Department.

Since 1943 a series of systematic investigations on Delaware's water resources have been made cooperatively by the State and Federal governments, represented primarily by their respective Geological Surveys. The results of these investigations are described in a series of reports, most of which have been published by the Delaware Geological Survey or the U. S. Geological Survey. These reports which are listed in Appendix II constitute the bulk of factual information available on Delaware's water resources.

The kind of information available on the water resources of Delaware and the areas covered by previous investigations are shown in figure 7. In general, the broad features of geology and hydrology of the State are known. In addition, more detailed studies have been made in two areas, northern New Castle County and Sussex County. The reports on these areas are adequate to answer, within a reasonable degree of accuracy, questions concerning the availability of water such as the character and distribution of streamflow, the depth and yield of the principal water-bearing zones, and gross features of the quality of both ground and surface waters. Such descriptive information, however, is not adequate to permit planning large-scale water developments or to determine the long-term effects of such development.

Concurrently with the State-wide and County investigations, studies have been made and reports prepared on areas where critical problems were known to exist or seemed imminent. Examples of these are (1) The ground-water resources of the Newark area, published by the Delaware Geological Survey as Bull. 2, (2) Ground-water conditions at the Dover Air Force Base, published by the Delaware Geological Survey as Report of Investigations No. 2, and (3) Wells for the observation of chloride and water levels in aquifers that cross the Chesapeake and Delaware Canal, published by the Delaware Geological Survey as Report of Investigations No. 3.

Besides the interpretive reports already mentioned, the Federal-State cooperative program has contributed a sizeable amount of basic water records. These data include records of streamflow, water-level fluctuations, and water-quality observations and are generally available in published form. Records of streamflow are published by the U. S. Geological Survey in annual issues of a series of Water-Supply Papers entitled "Surface-Water Supply of the United States, Part Ib, North Atlantic Slope Basins." Similarly, water-level records are published by the Delaware Geological Survey in an annual series of water-level reports. Data on water quality, including the sediment load of Brandywine Creek and the salinity of the Delaware River, are summarized in reports submitted annually to the Delaware Geological Survey. The network sites for which records are available are shown in figure 8.

The greatest deficiency of water records in Delaware is in the field of water quality, both chemical and physical. For this reason a quality of water program should be undertaken immediately. The initial investigation should include a State-wide reconnaissance of the quality of surface and ground water. The findings of the reconnaissance will provide a first approximation of water quality in the State and will be the basis for design of a quality of water network.

LONG-RANGE PLAN

Most, if not all, the water problems plaguing the State of Delaware are either caused by or aggravated by the lack of hydrologic or geologic infor-

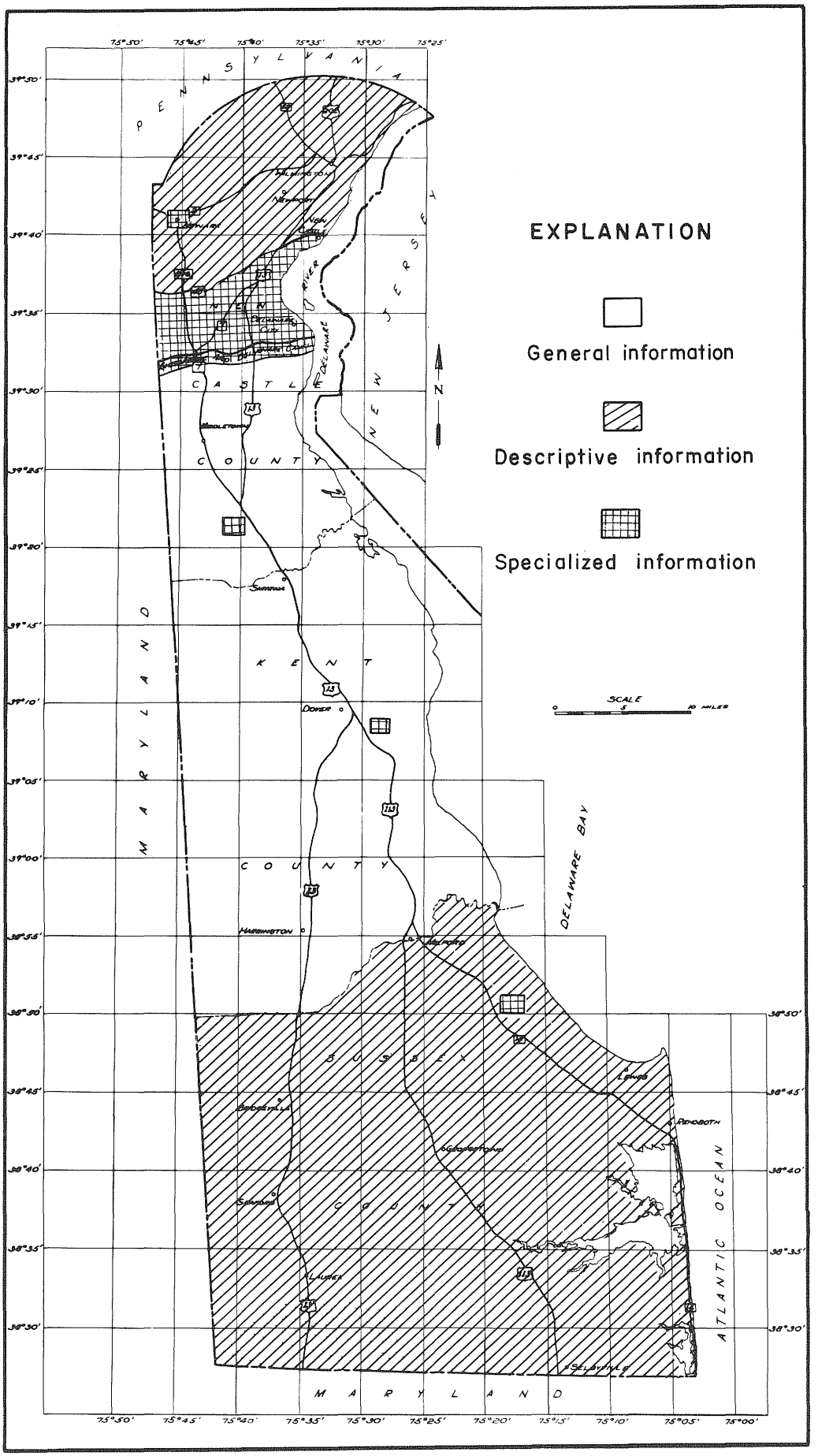

Figure 7. - Scope of information available on the water resources of Delaware.

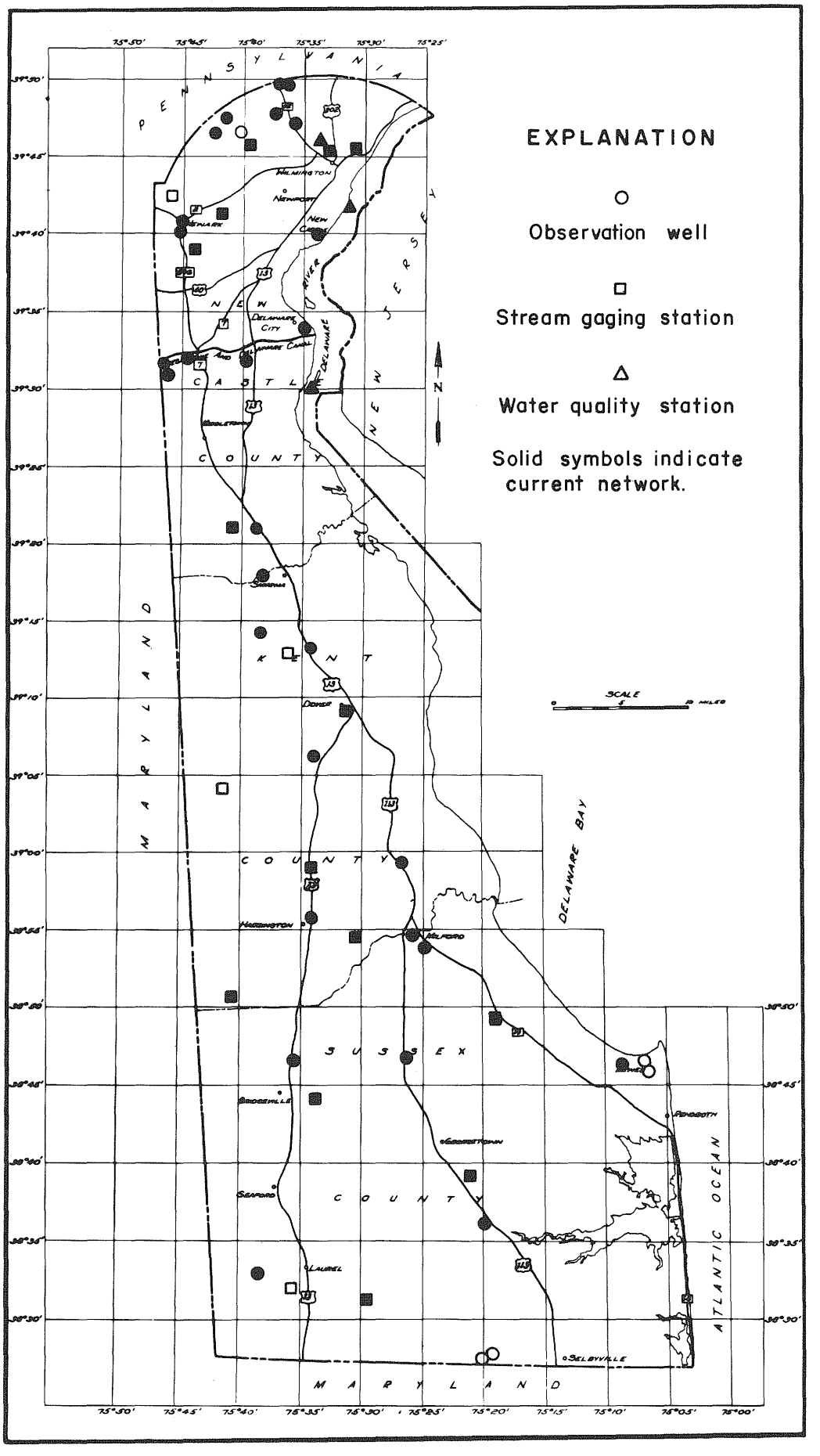

Figure 8. - Network for the collection of water records in Delaware.

mation. Therefore, many of the problems can be avoided, or at least alleviated, if systematic investigations are made prior to the development of additional supplies. In view of the tremendous expansion of water-supply facilities that will be needed if the State is to realize its potential growth during the next several decades, it is imperative that steps be taken to insure the availability of adequate information for the efficient and economical development of Delaware's water resources.

OBJECTIVES AND AIMS

The objective of this long-range plan is to set forth an orderly procedure for the investigation of the occurrence, availability, quantity, and quality of the water resources of Delaware in order that the most effective methods for their development and conservation may be determined. The plan includes the collection of pertinent basic data, the analysis and interpretation of these data, and research into those fundamental phases of hydrology that appear to have a bearing on the water resources of the State. The results of the investigations will be set forth in a series of published reports in order that they may be generally available to the public.

In general, the procedure will be to work from the broad general investigation to more and more detailed studies. This applies both to the extent and to the intensity of the investigations. The normal sequence will proceed from State-wide reconnaissance to more detailed reconnaissance in specific areas or drainage basins, and then to still more intensive investigations of problem areas or of potentially productive underdeveloped areas. The urgency of specific problems will generally require that some more detailed studies be made concurrently with the various phases of reconnaissance. It is intended that the program shall be flexible in its details so that its execution can be modified or accelerated to meet changing conditions.

KINDS OF INVESTIGATIONS

The objectives of this plan can be fulfilled by the orderly prosecution of a systematic program of water resources investigations comprising three general types of study. These include the collection of pertinent water records, the study of the hydrology of finite areas within the State, and research into those fundamental phases of hydrology and geology that appear to have a bearing on the water resources of the State. These three types of investigations are shown diagrammatically in figure 9 and discussed briefly below.

Collection of Water Records

An essential part of any future program of investigations is the establishment and maintenance of an adequate State-wide system for the collection of water records. It should be set up on a continuing basis and should include the collection of essential information on the flow of surface streams

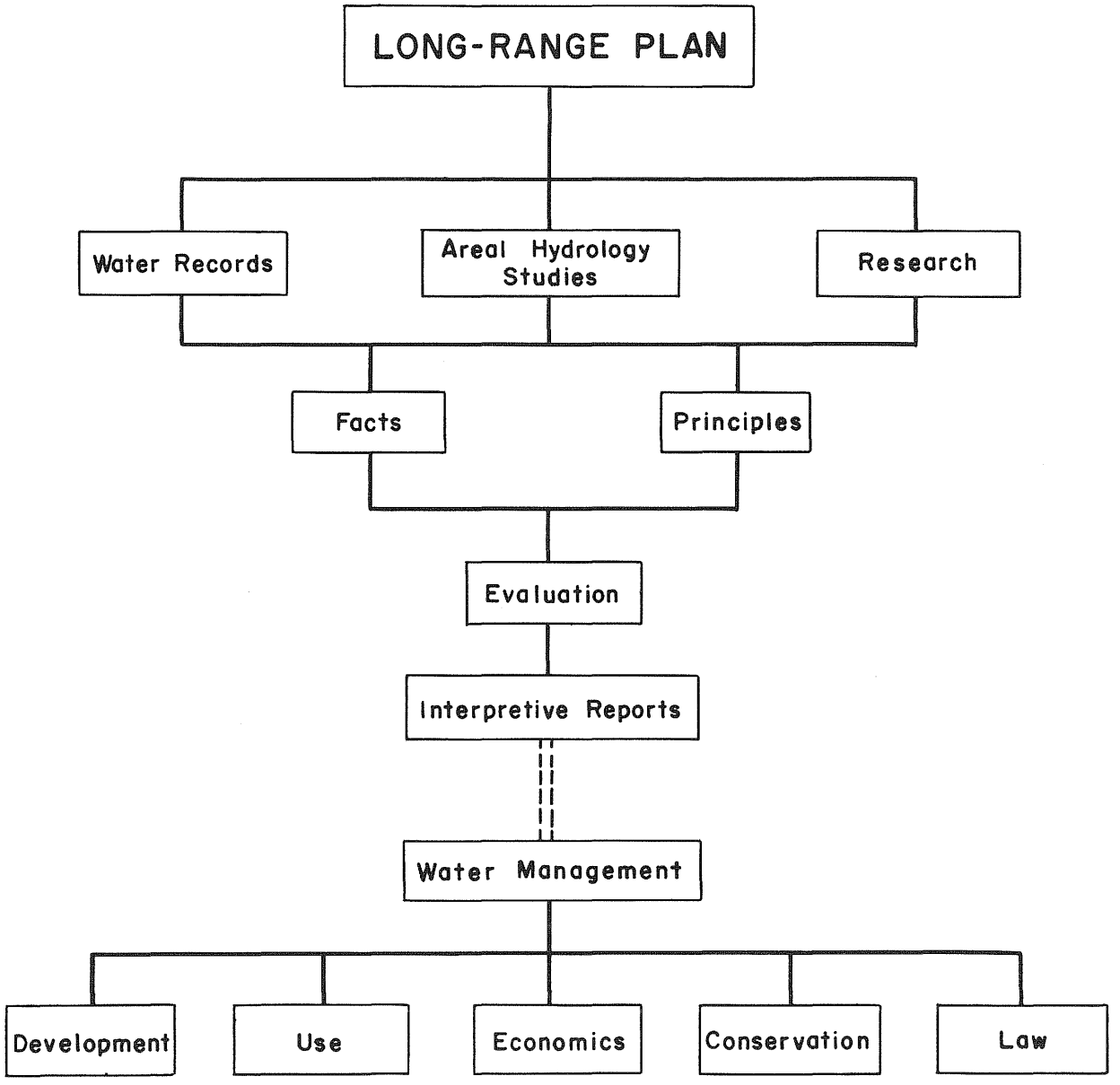

Figure 9. - Elements and objectives of the long-range plan.

and the fluctuations of ground-water levels, both natural and as affected by pumping. It should include the collection of increasingly detailed information on the use of water in the State and the quality of both ground and surface water and the factors that control it. Like other parts of the program, the collection of basic data should be subjected to frequent periodic review to check its content and direction and to ensure its adequacy.

Records of water use are becoming increasingly important as industrial development and population growth place more demands on total water supply. The trend in increased use per capita is also an item to be considered in projections of future water needs. As the limit of economical development of water supply is approached, it will be necessary to consider water use in determining allocation of the supply. Although controlling legislation has not been enacted in Delaware to enable State agencies to require records of use, it is important to improve present methods of determining approximate data. Without reasonably accurate records of diversions, regulation, losses, and return of flow, surface-water records lose much of their value except for determining current supplies at gaging station sites. Provision should be made to collect accurate records of use at least for all primary and secondary gaging stations. Some data on use of ground water are available; however, the water-use program should provide for more complete coverage. The effect of use on quality of both surface and ground water should be included in the program. Standardization of methods and publication of data are of utmost importance in developing a program of water-use investigations.

Areal Hydrology Studies

Studies of finite areas or basins fill the need for detailed water information where existing knowledge is inadequate to provide for the optimum use of available water supplies. The objective of this type of investigation will be to obtain the basic water facts needed for the orderly development and sustained use of the water resources available in the area of study. This will involve an appraisal of the quantity and distribution of surface water supplies; quantity, extent, and safe yield of ground-water supplies; and the quality of both surface and ground water.

Much of the basic information needed to determine the quantity and distribution of surface water will be provided by the collection of streamflow records. However, effort should be devoted to the appraisal of these records as they relate to the development and use of water supplies. Studies of low-flow frequency, flow duration, and storage requirements are essential to the proper design of water-supply facilities. Streamflow records in most of Delaware are of relatively short duration, but the data should be analyzed periodically to permit full use of the available information.

Areal studies of the quantity, extent, and safe yield of ground-water supplies are needed to keep pace with the ever-continuing demand for ground water, particularly in the Coastal Plain section of the State. The objectives

of these studies are to delineate and define all the aquifers within economic reach of wells and to evaluate the effect of development on the ground-water regimen. To accomplish these objectives it will be necessary to collect subsurface geologic data to determine the areal extent and depth of all water-bearing zones. Attention will be focused on the texture, thickness, and continuity of aquifers as a means of interpreting the potential capacity of each aquifer to yield water.

Studies of the quality of both ground and surface water will be an integral part of each areal hydrology project. Such information is vitally important because natural waters acquire chemical and physical properties which ultimately determines their suitability for various uses. Chemical quality standards for water to be used for domestic, agricultural, and industrial purposes have been published by the U. S. Public Health Service, the Department of Agriculture, and other agencies. Water that does not meet these standards should not be used unless the users of such water are prepared to meet the difficulties involved. Likewise, the physical properties of natural water are important in the planning and design of water-supply and water-control facilities. For example, needless and costly difficulties are incurred if, in the design of a surface reservoir, allowances are not made for the sediment load of the stream entering the reservoir. This and other problems can be averted if adequate information is available on the quality of water in Delaware's streams and underground reservoirs.

Research Studies

Research in hydrology and the closely related science of geology seeks to improve our understanding of the complex phenomena related to water upon the surface and underground. Hydrologic research deals with the physical laws and processes involved in various phases of the hydrologic cycle, a term used to designate the endless circulation of water from the land, to the sea, to the clouds, and back again to the land. Geologic research, on the other hand, is concerned with the natural environment through which water passes on its endless journey. Detailed knowledge of both the hydrologic and geologic features controlling the occurrence and movement of water are prerequisite to an adequate understanding of water problems.

Certain features of the hydrologic environment in Delaware have received little or no attention in the past. Some of these features, such as the presence of numerous small lakes and ponds and the proximity of the State to bodies of saline or brackish water, may have a direct influence on the quantity and quality of local water supplies. Other features, such as the extensive sand and gravel aquifers in the Coastal Plain section of the State and the large areas of poorly drained land, may have a profound influence on future land-use practices. Consequently, research studies should be undertaken to determine the potential value of these unusual features in relation to water resources and current land-use practices.

One of the first investigations that should be undertaken in this category is a study of the effects of small lakes or ponds on the quantity and quality of local water supplies. The correct identification of these effects will require a comparative study of two identical areas or small drainage basins; one having no obstruction to natural drainage and the other having an impounding dam. Sufficient geologic and hydrologic data will need to be collected to appraise both the differences and similarities in the effective hydrologic systems in each area. An attempt will then be made to interpret these data in quantitative terms.

An important part of the research program is the investigation of saline-water encroachment, both actual and potential. Previous studies indicate that substantial parts of the shallow aquifer along the eastern coast of Delaware have been invaded by saline water and other aquifers are threatened in some places. A study of specific instances of saline-water encroachment and the determination of the relative stability or instability of the salt-water front with respect to the existing pattern of development will provide the facts necessary to control this serious threat to the future fresh-water supplies in the coastal areas of Delaware.

Research studies of the major aquifers in Delaware will provide a more complete understanding of the occurrence of ground water on a regional basis. These studies will produce a complete description and analyses of the geologic dimensions and hydrologic properties of each of the major aquifers in Delaware. In this way local anomalous conditions can be brought to light and attention can be focused on specific problems relating to individual aquifers and their use as a source of supply. This information will make possible the maximum development of the ground-water resources of the State.

Numerous other subjects will need to be explored as the search for water to satisfy Delaware's future needs increases in complexity. The possibility of developing water supplies in connection with drainage improvement programs should be thoroughly explored. Experiments should be made of the feasibility of artificial recharge in areas of deficient water supplies. Ways of reducing water losses to evaporation and transpiration should also be considered.

In short, we are far from knowing how best to use and manage Delaware's water resources. The most logical means of overcoming this difficulty is through research.

IMPLEMENTATION

The long-range program will be implemented by means of a series of projects, each dealing with some phase of the water resources of the State, and each including the preparation of a report for publication. A list of projects with suggestions as to their approximate order of priority is presented in Appendix I. This list and the priority of projects within it will be

subject to periodic review no less frequently than every two years. Generally each project will be so designed that the manuscript of a report can be completed, ready for technical review, within three years, and preferably within two years. Projects that inherently involve a longer period of investigations will result in progress reports no less frequently than every three years. Once a project has been undertaken every effort will be made to avoid interruptions that will extend its duration. The necessity for such interruptions will be inversely proportional to the logic and comprehensiveness of the schedule of projects.

Reports on the investigations resulting from the prosecution of this program will be published in a manner that will make them most widely and generally available to interested individuals. Subsequent to their completion as a part of scheduled projects they will be reviewed and revised if necessary so that they will be reasonably complete and adequate for the purpose for which they are intended.

It is anticipated that few, if any, of the reports contemplated in this plan will be final reports. Continued development and industrial and municipal growth within the State will result in man-made changes in conditions that will effect the water resources and their use. It will, therefore, be essential to collect new data continuously, to re-evaluate existing data, and to analyze and report upon them periodically. For example, following the initial report on an individual county, additional progress reports may be necessary on the same county at intervals ranging from four to ten years. It will probably be desirable, also, to prepare a revised summary of groundwater conditions for the entire State at intervals of approximately ten years in order to present the more detailed information that has become available and to relate it to the effects of human activities.

CONCLUSIONS

The program outlined in the preceding pages is designed to accomplish an orderly appraisal of Delaware's water resources. It can be implemented to a degree that is proportionate both to the need and to the funds available. The State and Federal interests demand the best possible program with the broadest coverage. It is believed that the systematic implementation of the plan proposed herein will yield the maximum benefits in the form of reliable water knowledge on which the people of Delaware can base wise plans for the water development, use, and conservation of their water supplies.

In view of the importance of water to the economy of the State and the volume of effort still needed to evaluate its water resources, it is believed that water investigations should be continued in Delaware on an expanded scale. To be effective, the investigative program should be of such size so as to insure a rate of achievement commensurate with the need for water information now and in the immediate future.

In general it is believed that both the State and Federal government will have an interest in most of the projects proposed herein. Some will also be of significant interest to certain county or municipal units. Prior to the initiation of any project however, it is expected that each agency will determine the degree of its interest and participation in it. To this end the scope, objectives, and limitations of each project will be defined as clearly as possible at the time it is proposed for activation. Any significant changes in the scope, objectives, or limitations of the project after its initiation will also be a matter of common understanding. The sum of all the projects outlined in this plan and of such others as may be initiated hereafter, constitutes the long-range program for water investigations in Delaware.

APPENDIX I

SCHEDULE OF PROJECTS

The priority of individual projects is determined largely by two factors, the urgency of the need for the results of the project and the extent to which the data obtained will facilitate future projects. Hence, any list of projects in order of their priority is subject to review and revision from time to time to insure the fulfillment of the needs of the State for water facts.

In the schedule of projects that follows, those projects with the highest overall priority are placed first on the list. Highest priority is given to projects already in progress. Following the overall listing, a somewhat detailed description is presented of projects that now seem to demand high priority.

Projects Already in Progress

1. Collection of water records
   a. Water levels and artesian pressures
   b. Streamflow
   c. Sediment load in the Brandywine
2. Water table and engineering soils mapping
3. Ground-water resources of southern New Castle County
4. Salinity of the Delaware estuary

List of Proposed Projects in Order of Priority

A. State-wide reconnaissance of the quality of surface and ground water
B. Saline-water encroachment along the Sussex County shoreline
C. Quality of water network investigation
D. Water resources of Kent County
E. Water utilization (State-wide)
F. Hydrology of the Pleistocene sediments in Sussex County
G. Reappraisal of the ground-water resources of New Castle County with special reference to the non-marine Cretaceous sediments

H. State-wide flood frequency study
I. Effects of small lakes and ponds on the availability and quality of water resources
J. Saline-water encroachment in Kent and New Castle Counties
K. Flood plain inundation mapping (northern Delaware)
L. Hydrology of the Pleistocene channel deposits in New Castle County
M. State-wide low flow analyses
N. Hydrology of the Miocene sediments in Kent and Sussex Counties
O. Feasibility of artificial recharge in New Castle County
P. Hydrology of the Eocene sediments in southern New Castle and Kent Counties

DETAILED DESCRIPTION OF HIGH PRIORITY PROJECTS

State-wide Reconnaissance of the Quality of Ground and Surface Waters of Delaware

Purpose: To establish the basic knowledge of the chemical composition of the natural waters of Delaware in order to facilitate the operation of a State-wide base network.

Methods: Very little chemical or physical quality data is available for the State of Delaware. Therefore, this initial effort will comprise a State-wide reconnaissance investigation of the quality of water available from both streams and ground-water reservoirs. Chemical quality and sediment samples will be collected and analyzed in the laboratory. The data obtained from stream samples will be appraised on the basis of recommendations set forth by the committee on criteria for selecting surface-water quality base network stations. The data on ground-water quality will be used to identify the general character of the ground water, both areally and with depth.

Time of Completion: This project can be completed in one man-year.

Saline-water Encroachment Along the Sussex County Shoreline

Purpose: To prepare a map showing position of the saline-water fresh-water interface and to determine the relative stability of the front with respect to the existing pumping regimen.

Methods: 1. Determine the dimensions and physical character of the principal aquifer in the area through test drilling, well canvassing, and geophysical techniques.

2. Determine the position of the salt-water interface within the principal aquifer by means of chemical analyses of samples and other methods of determining the chloride content of water.

3. Determine the effects of pumping on the movement of the salt-water front.

4. Draw conclusions as to the best methods of protecting and conserving the available supply.

Time of Completion: Three man-years of effort will be required to accomplish these objectives. Conceivably, the results could be made available in two years provided two people are assigned to work on this project without interruption.

Water Resources of Kent County

Purpose: To determine the availability, quantity, and chemical quality of the ground water within economic reach of wells.

Methods: 1. Inventory in detail all ground-water supplies in the area and record the source and magnitude of withdrawals from wells.

2. Explore with test wells and electric logs in areas where geologic and hydrologic data are needed.

3. Study the drill cuttings and electric logs from wells in order to determine the physical character and extent of the aquifers in the area, and plot these data on detailed geologic-structure maps and geologic cross-sections.

4. Determine the chemical character of the water in the principal aquifers and relate it to the geologic factors that control its occurrence and movement.

5. Collect water-level data in key wells and evaluate this data in terms of the hydrologic regimen, the magnitude of the seasonal fluctuation of water levels, and the effects of sustained ground-water withdrawals on water levels and on the surface water of the area.

6. Make pumping tests to determine the hydraulic properties of the principal aquifers, the area influenced by the withdrawal of water from the aquifers, and the relation of pumping to the proper spacing of wells.

7. Analyze and interpret all available data and prepare a report that can be used as a basis for planning municipal, industrial, and individual development of the area's ground-water resources in an orderly manner.

Time of Completion: Approximately six man-years of effort will be required to complete this project. Preferably, two men should be assigned to this project and at least one of them should have considerable ground-water experience. If so, the results would be available three years after initiation.

Hydrology of the Pleistocene Sediments in Sussex County

Purpose: The purpose of this study is to determine all of the factors of the hydrologic environment affecting the occurrence of ground water in the shallow unconfined aquifer in Sussex County.

Methods: 1. Determine the area extent, texture, thickness, and continuity of the principal water-bearing zones in the Pleistocene sediments.

2. Determine the pattern of ground-water circulation in the Pleistocene sediments including the direction of movement, and location of areas of discharge.

3. Determine the significant chemical characteristics of the water in the Pleistocene sediments.

4. Interpret these data in terms of the quantity and quality of water available and the most efficient methods of developing and maintaining satisfactory supplies.

Time of Completion: It is estimated that the completion of this study will require approximately six man-years of effort. To shorten the period of study, at least two men should be assigned to work on this project. The results would then be available in three years after the project is initiated.

The Effects of Small Lakes and Ponds on the Availability and Quality of Local Water Supplies

Purpose: To test the hypothesis that local ground-water supplies are benefited by the presence of small surface reservoirs.

Methods: 1. Explore with test wells and electric logs the geologic and hydrologic features of two small areas, one adjacent to a surface reservoir and the other near an unobstructed stream.

2. Analyze these data and determine the relative significance of any dissimilarities between the two areas.

3. Collect water-level data and prepare contour maps showing the configuration of the water table at selected intervals of time.

4. Make aquifer tests in both areas to determine the response of the hydrologic systems to withdrawals from wells.

5. Conduct a surface inflow-outflow study in each area to determine the magnitude of ground-water discharge under natural conditions and the amount of induced recharge available.

6. Determine the chemical character of both the ground water and surface water, and interpret the results in terms of the ultimate effect of induced recharge on the chemical quality of the available supply.

7. Compare the results obtained from the experimental area with that from the control area and prepare a report describing the differences with respect to the quantity and quality of water available.

Time of Completion: It is estimated that this project could be completed in three years by a professional geologist with a part-time assistant.

APPENDIX II

GEOLOGIC AND HYDROLOGIC REPORTS IN DELAWARE

Reports Published by the Delaware Geological Survey

Bulletin 1. Ground-water problems in highway construction and maintenance, by W. C. Rasmussen and L. B. Haigler. 1953. 24 p.

Bulletin 2. Geology and ground-water resources of the Newark area, Delaware, by J. J. Groot and W. C. Rasmussen, with a section on the surface-water resources by A. E. Hulme. 1954. 133 p.

Bulletin 3. Marine Upper Cretaceous formations of the Chesapeake and Delaware Canal, by J. J. Groot, D. M. Organist, and H. G. Richards. 1954. 64 p.

Bulletin 4. Preliminary report on the geology and ground-water resources of Delaware, by I. W. Marine and W. C. Rasmussen. 1955. 336 p.

Bulletin 5. Sedimentary Petrology of the Cretaceous sediments of northern Delaware in relation to paleogeographic problems, by J. J. Groot. 1955. 157 p.

Bulletin 6. The water resources of northern Delaware, by W. C. Rasmussen, J. J. Groot, R. O. R. Martin, E. F. McCarren, and others, with a special section on problems of water management by Vaughn C. Behn. 1957. 223 p.

Bulletin 7. Engineering materials of northern New Castle County, by R. F. Ward and J. J. Groot. 1957. 103 p.

Bulletin 8. Water resources of Sussex County, Delaware -- A progress report, by W. C. Rasmussen, R. A. Wilkens, and R. M. Beall. 1961. 250 p.

Report of Investigations No. 1. Salinity of the Delaware estuary, by B. Cohen. 1957. 85 p.

Report of Investigations No. 2. High capacity test well developed at the Air Force Base, Dover, Delaware, by W. C. Rasmussen, J. J. Groot, and A. J. Depman. 1958. 36 p.

Report of Investigations No. 3. Wells for the observation of chloride and water levels in aquifers that cross the Chesapeake and Delaware Canal, by W. C. Rasmussen, J. J. Groot, and N. H. Beamer. 1958. 22 p.

Water-Level Report No. 1. Water levels and artesian pressures in Delaware, 1952, by I. W. Marine. 1954. 11 p.

Water-Level Report No. 2. Water levels and artesian pressures in Delaware, 1953, by D. H. Boggess and O. J. Coskery. 1955. 10 p.

Water-Level Report No. 3. Water levels and artesian pressures in Delaware, 1954, by O. J. Coskery and D. H. Boggess. 1956. 10 p.

Water-Level Report No. 4. Water levels and artesian pressures in Delaware, 1955, by O. J. Coskery. 1957. 9 p.

Water-Level Report No. 5. Water levels in Delaware, 1956, by O. J. Coskery and W. C. Rasmussen. 1958. 16 p.

Reports Published by the U. S. Geological Survey

Water-Supply Paper 1016. Water levels and artesian pressures in observation wells in the United States in 1944, pt. 1, Northeastern States, chapter on Delaware, by G. D. DeBuchananne. 1947. p. 23-24.

Water-Supply Paper 1023. Water levels and artesian pressures in observation wells in the United States in 1945, pt. 1, Northeastern States, chapter on Delaware, by G. D. DeBuchananne. 1948. p. 20-21.

Water-Supply Paper 1071. Water levels and artesian pressures in observation wells in the United States in 1946, pt. 1, Northeastern States, chapter on Delaware, by G. D. DeBuchananne. 1949. p. 18-19.

Water-Supply Paper 1096. Water levels and artesian pressures in observation wells in the United States in 1947, pt. 1, Northeastern States, chapter on Delaware, by J. M. Birdsall. 1951. p. 19-20.

Water-Supply Paper 1126. Water levels and artesian pressures in observation wells in the United States in 1948, pt. 1, Northeastern States, chapter on Delaware, by J. M. Birdsall. 1951. p. 17-18.

Water-Supply Paper 1156. Water levels and artesian pressures in observation wells in the United States in 1949, pt. 1, Northeastern States, chapter on Delaware, by J. M. Birdsall. 1952. p. 16-17.

Water-Supply Paper 1165. Water levels and artesian pressures in observation wells in the United States in 1950, pt. 1, Northeastern States, chapter on Delaware, by G. E. Andreasen. 1953. p. 9-17.

Water-Supply Paper 1191. Water levels and artesian pressures in observation wells in the United States in 1951, pt. 1, Northeastern States, chapter on Delaware, by I. W. Marine and W. C. Rasmussen. 1954. p. 11-16.

Water-Supply Paper 1221. Water levels and artesian pressures in observation wells in the United States in 1952, pt. 1, Northeastern States, chapter on Delaware, by I. W. Marine. 1954. p. 11-18.

Water-Supply Paper 1265. Water levels and artesian pressures in observation wells in the United States in 1953, pt. 1, Northeastern States, chapter on Delaware, by D. H. Boggess and O. J. Coskery. 1955. p. 13-22.

Water-Supply Paper 1321. Water levels and artesian pressures in observation wells in the United States in 1954, pt. 1, Northeastern States, chapter on Delaware, by O. J. Coskery and D. H. Boggess. 1956. p. 13-22.

Water-Supply Paper 1404. Water levels and artesian pressures in observation wells in the United States in 1955, pt. 1, Northeastern States, chapter on Delaware, by O. J. Coskery. 1957. p. 13-21.

Journal Articles

Maryland-Delaware Water and Sewage Assoc., Proc. 28th Annual Conf., Magnitude of the ground waters of Delaware, by W. C. Rasmussen. 1955. p. 53-66.

Delaware Intrastate Water Resources Survey, Ground-water Availability in Delaware, by J. J. Groot. 1959. p. 15-3 - 15-17.

Bulletin of the Geological Society of America, Vol. 70, Petrology and Metamorphism of the Wilmington Complex, Delaware, Pennsylvania, and Maryland, by R. F. Ward. 1959. p. 1425-1458.

Jour. American Water Works Assoc., Feasibility of artificial recharge at Newark, Delaware, by C. R. Groot. 1960. p. 749-755.

Micropaleontology, vol. 6, no. 2, Plant microfossils and age of nonmarine Cretaceous sediments of Maryland and Delaware, by J. J. Groot and J. S. Penny. 1960. p. 225-236.

Proceedings, Seventh National Clay Conference, Some aspects of the mineralogy of the northern Atlantic Coastal Plain, by J. J. Groot and H. Glass. 1960. p. 271-284.

Open-File Reports

A search for aquifers of sand and gravel by electrical resistivity methods in north-central New Castle County, Delaware, by H. C. Spicer, R. A. McCullough, and F. K. Mack. 1958. 18 p.

The geology of the Wissahickon formation in Delaware, by R. F. Ward. 1956. 59 p.

Reports Awaiting Publication

U. S. Geological Survey Water-Supply Paper. Geology and hydrology of the "bays" and basins of Delaware, by W. C. Rasmussen. 206 p.

Delaware Geological Survey Water-Level Report No. 6. Water levels in Delaware, 1957, by O. J. Coskery. 14 p.

Delaware Geological Survey Water-Level Report No. 7. Water levels in Delaware, 1958, by O. J. Coskery. 14 p.

Plant microfossils and Age of the Raritan, Magothy and Tuscaloosa formations of the Eastern United States, by J. J. Groot, J. S. Penny, and C. R. Groot.