DELAWARE

Water

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Report based mainly on work accomplished cooperatively with the Delaware Geological Survey, the Delaware State Highway Department, and other County, Municipal, and Federal agencies

Geological Survey Water-Supply Paper 1767

Brandywine Creek, in the Fall Zone, near Wilmington, Del.
(Courtesy of Chamber of Commerce, Delaware, Inc.)

DELAWARE WATER

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

FIGURES

THE SIGNIFICANCE OF WATER

Water Is Essential

Water is necessary and most vital, yet it is the least expensive major resource we have. More than 70 percent of the surface of the earth is covered with water. In some of the ocean deeps, water extends to depths greater than 6 miles. Beneath the land masses, water is believed to fill the crevices and crannies of some rocks to even greater depths.

Even in the atmosphere, water is most important. Although by weight and by volume water generally constitutes less than 5 percent of the atmosphere, the transfer of water by evaporation from the ocean to storm clouds and, thence, to precipitation on the land is the great heat regulator of the environment of life, a thermostat controlling temperature and other climatic conditions. Upon the small percentage of atmospheric water, the life cycle of plants, of animals, and of man himself depends.

Water Is Life!

Where there is no water, there is no life. The barren desert regions of the earth support little or no life because of the scarcity of water. The lifeless face of the moon changes very slowly because of the lack of water and atmosphere.

Water Is Life to Plants

Water is the dominant constituent of every living thing. The lowly one-celled organisms that represent the simplest and most primitive forms of life are more than 90 percent water by volume and by weight. Trees are almost three-fourths water by weight. Even more significant is the amount of water used in life processes; that is, the water evaporated in cooling and the water transpired in plant growth. One thousand pounds of water may be used in making a single pound of dry wood.

Water, carbon dioxide, and radiant energy from the sun are combined in the process of photosynthesis to form cellulose, the chief tissue in plants. A green substance, chlorophyll, is an essential agent in the process, serving as a catalyst—the term a chemist uses for substances that change the speed of a chemical reaction but are not consumed in the process. Without chlorophyll, the reaction or growth, would be so slow that a man in his lifetime could not detect a change; with the green catalyst, however, growth is observable within hours, and even minutes.

WATER CONSUMED IN GROWTH:

365 pounds for 1 pound of corn

WATER STORED:

Apples 87 percent
Potatoes 75 percent

Plants are composed chiefly of water.

Every tree, every bush, every tussock, every rooted blade of grass is a well, drinking water from the soil and transpiring it to the atmosphere. Of the 1,800 billion gallons of fresh water that precipitates upon Delaware in the average year, the writers estimate that about 67 percent, or 1,200 billion gallons, is evaporated from the soil or transpired by plants.

Water Is Life to Animals

Animals drink water and eat plants and other animals. The chain of life of the animal kingdom has even greater dependency on water than does that of the plant kingdom because most animals are moving, active creatures, and this activity requires the drinking and exhalation of relatively more water than a rooted plant of the same weight. Perspiration, the discharge of water for cooling, is an important function.

The equation of photosynthesis is reversed when animals eat plants and burn the carbohydrates to derive energy. Oxygen is inhaled, and the carbohydrate is oxidized to water and carbon dioxide, which are exhaled as waste products of combustion. Body substances known as enzymes are catalysts.

The animal population uses about 0.7 billion gallons of water a year, an almost insignificant fraction of the use by plants. Some of this water is not returned directly to the atmosphere but is discharged upon the soil, where its nitrogenous solutions are of value as fertilizer.

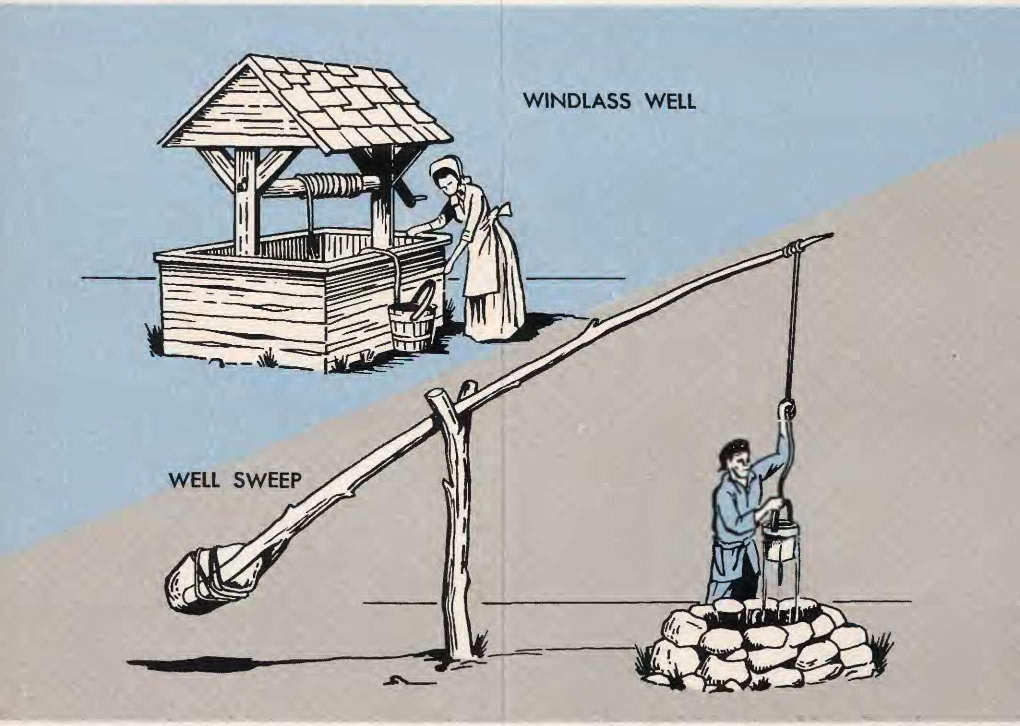
Water Is Life to Man

A man can go nearly 2 months without food, but he can live only 3 to 4 days without water. The average human body contains 12 gallons of water, weighing about 100 pounds, or two-thirds of the average weight. The average human must drink 3 quarts of water a day to make up water lost through perspiration and waste.

The history of the use of water by man is recorded in the pottery and implements found at archeological "digs." It is conjectured that prehistoric man in Delaware drank directly from streams, springs, or ponds and kept on the alert for natural enemies while he used the "waterhole." During the last ice age, these enemies were bears, wolves, great cats, and even the mammoth. About the beginning of Recent time—that is, about 10,000 years ago—man had learned to use shells, gourds, and animal skins to carry water to his tent or cave, where he could use it for cooking and washing, as well as for drinking. About 5,000 years ago the art of pottery making was developed, and jars and bowls were used to store water.

The American Indians in Delaware were too nomadic and water was too plentiful to make it necessary to develop wells. The first wells were probably sunk by early settlers at the sites of springs, which dried up late in summer, when the water table had receded only a few feet. During prolonged droughts these wells were dug deeper. The first casing consisted of timbers to shore up the sides of the hole. In the Piedmont area, rock was available to make a permanent well wall and to replace decaying timbers. Hollowed logs were used for the first water pipes, and some were tried as tubular casing in wells. About the year 1800, cast iron was tried for pipe and casing and thereafter replaced wood.

The first "pump" was a bucket on a rope. Some of the pioneer wells operated on the principle of a simple lever, using a "sweep" with a counterweight, a forked fulcrum,



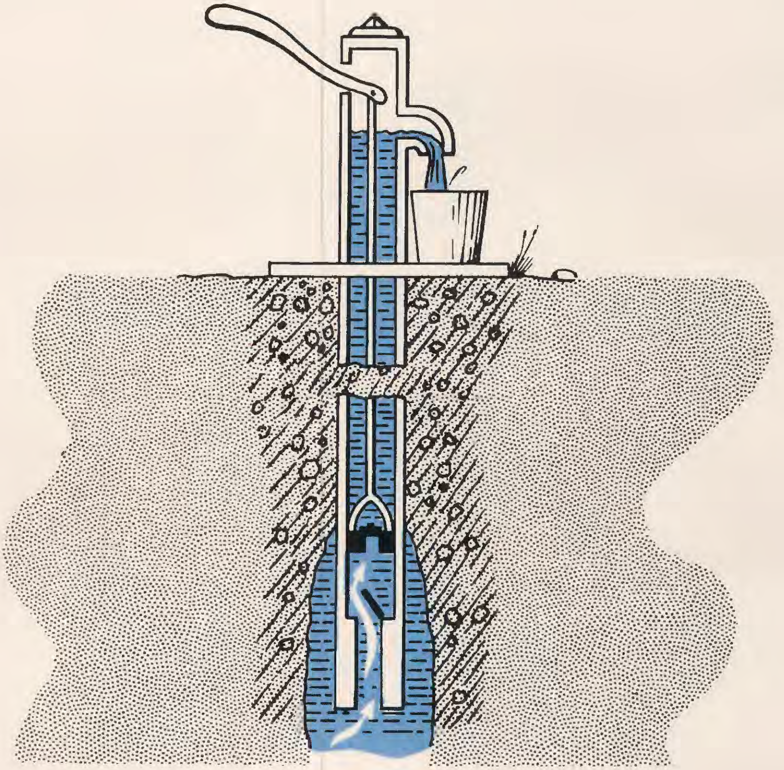
Pioneer and colonial wells.

The town pump.

and a rocker arm; others operated on the principle of the pulley, as do windlass wells. The principle of the hand suction pump had been developed in Europe in the Middle Ages, and windmills were invented to pump water by cylinder lift. By colonial times and in the early days of Statehood wells of these types were in use in Delaware.

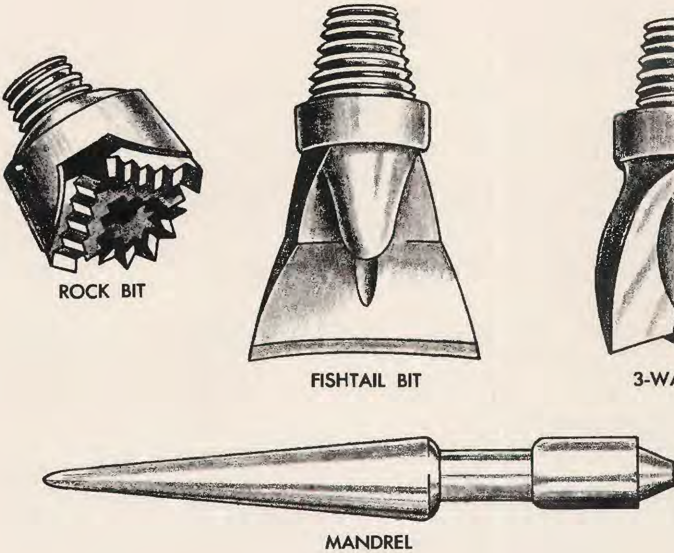
Waterpower was used in Delaware from colonial times through the 19th century to turn the millstones for grinding flour and, along Brandywine Creek, to grind powder.

During the 19th century, the cable-tool method for drilling wells in crystalline rock was developed. Forged iron bits made rock drilling possible. Late in the century, the method of jetting wells in the soft sediments of the Coastal Plain brought development of artesian wells within the economic means of many farmers. The well screen made it possible for the householder to have a relatively cheap, safe source of water by driving a perforated tube, called a drive point, down into the shallow water-bearing sands.

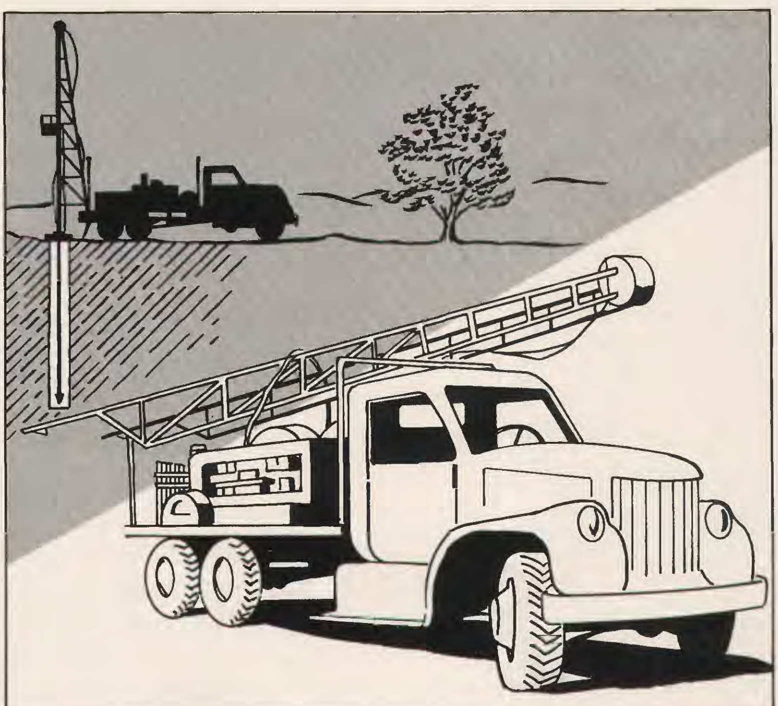


Section of a hand-suction pump.

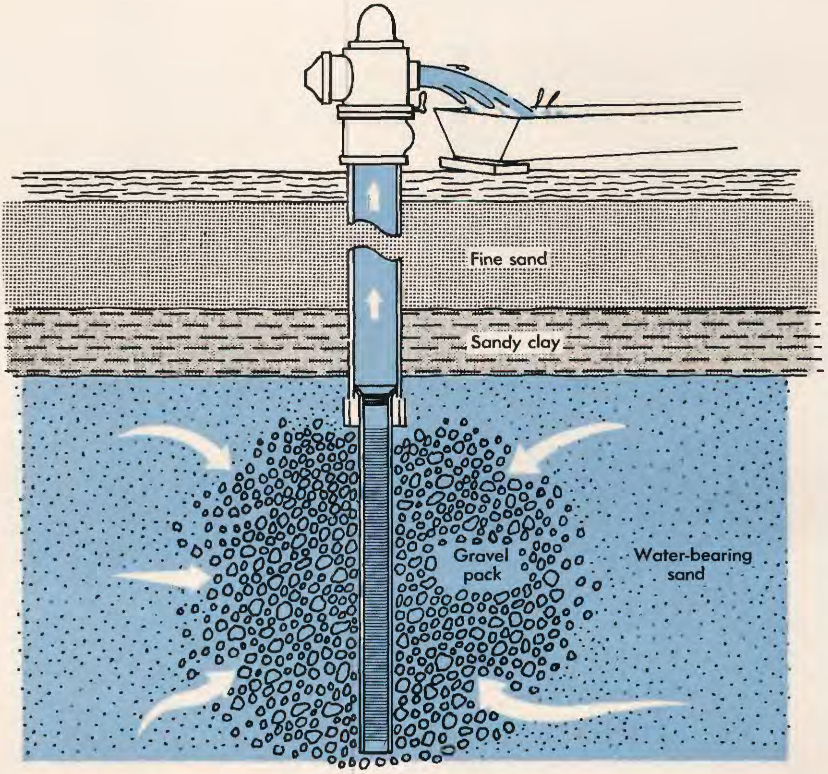
Mill for grinding flour or powder.



Drill bits.



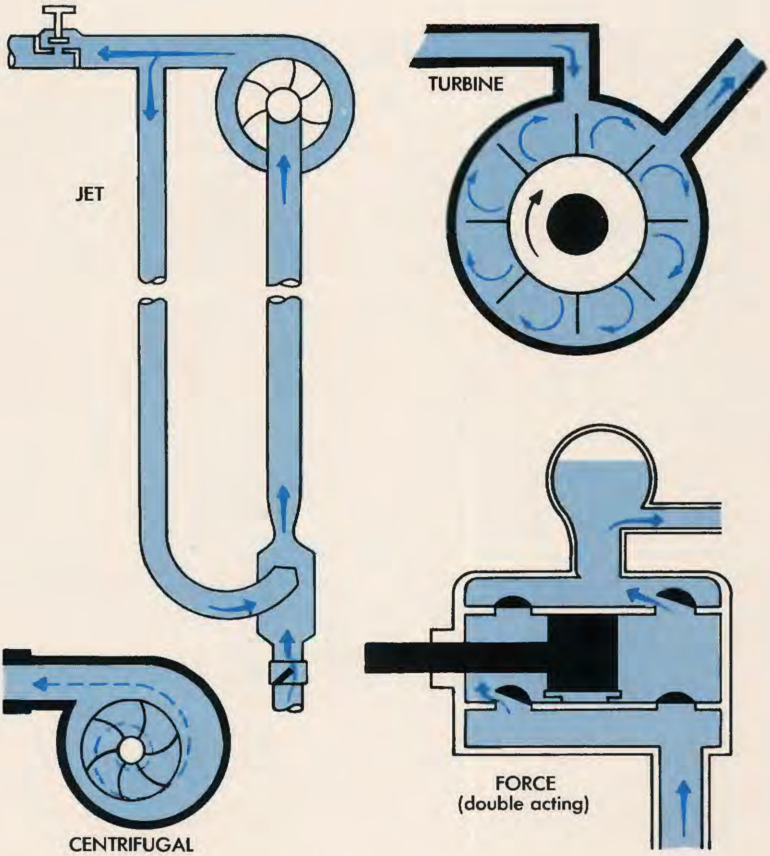
Drilling in Delaware.



A gravel-packed well.

Finally, rotary drilling, in which water and mud are pumped down the hollow drill rod to flush the cuttings, has resulted in the rapid construction of moderate- to large-capacity wells in soft water-bearing sedimentary rock. Wells in fine sands, in which the space outside the well screen is packed with fine gravel, produce more water with less drawdown than conventional wells.

The development of large quantities of water in Delaware, as in the rest of the world, awaited the invention of power and pumps that could do the job. Huge steam-powered reciprocating force pumps were the first able to move large quantities of water under high head. "Head" is the hydraulic term for the height of lift, or the pressure, against which a pump must work.



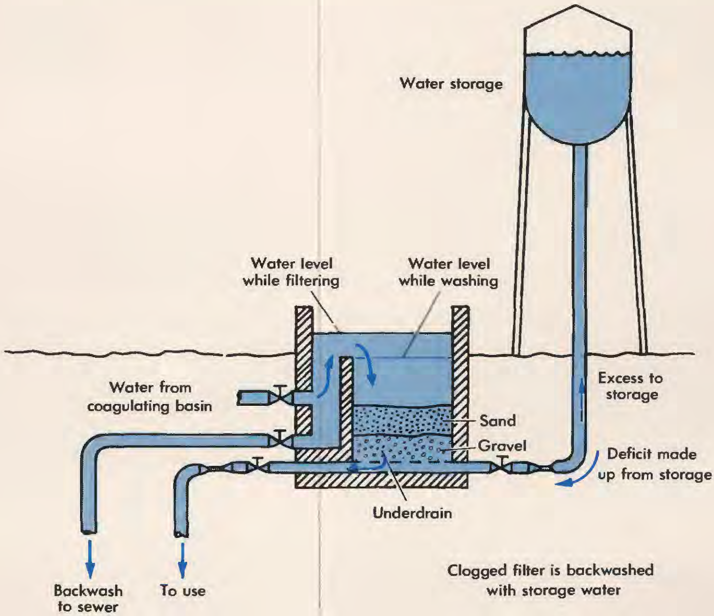
Machine-driven pumps.

Centrifugal pumps, with a spinning impeller, were developed, drawing water from the center and forcing it outward at high discharge and at high head. These pumps, however, were limited to about 25 feet of suction lift. The jet pump, recirculating part of the discharge to create a jet drive within the draw column, permitted higher lift on the suction side of the pump. Then turbine pumps, with the impeller immersed in the well and spun by a high-speed shaft, were developed for deep-well operation. Submersible electric pumps are now designed to be submerged near the bottom of the well, and thus the long rotating shaft necessary in older types is avoided.

Gasoline and diesel fuel-powered pumps provide compactness and mobility of installation. Electric-powered pumps provide even greater efficiency, reliability, and economy of space but are not mobile.

Ingenious as the development of mechanical equipment has been, the advance in water purification and control of water-borne diseases has been equally significant. Water-borne diseases common in lands where water sanitation is not practiced cause much discomfort and pain and sometimes illness and death in epidemic proportions. Typhoid and paratyphoid fever, diarrhea, and hepatitis occur in temperate climates; cholera, bacillary dysentery, amoebic dysentery, and schistosomiasis occur in subtropical and tropical climates.

The germs causing disease are carried in small particles of clay and organic material which can be removed by filtration. Filter systems usually use a coagulant, such as alum, to precipitate the particles on the surface of a bed of sand and gravel, through which the water drains and emerges clear. A rapid sand filter is illustrated below.



A rapid-sand-filter system.

The relative effect of sudsing hard water and soft water.

Chlorination is required for nearly all public water supplies. It was the process of chlorination, introduced in Delaware early in the 20th century, that finally reduced the incidence of water-borne disease almost to the vanishing point.

Some waters in central Delaware are hard or moderately hard, which means that they consume much soap in order to form a lather and that a greasy, rubbery curd is obtained from a compound of the soap and the minerals causing hardness. The hardness is due principally to the bicarbonates and sulfates of calcium and magnesium and, to a lesser degree, to aluminum and iron. Hard water makes the cost of laundering excessive, as illustrated by the meager suds obtained with soap in hard water compared to the abundant suds obtained with an equal amount of soap in soft water.

Hard waters can be softened by exchanging the calcium for the sodium.

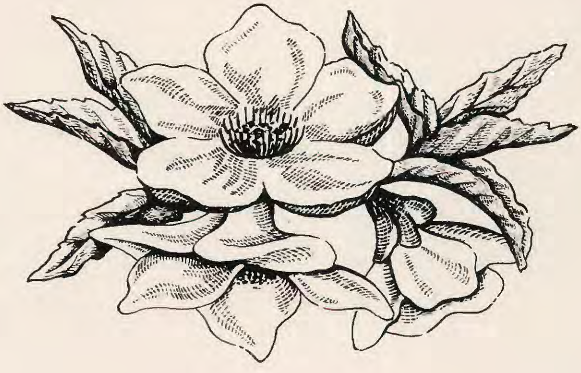
Some waters in Delaware contain a troublesome amount of iron. Even a small amount of iron can be a nuisance, as it stains fixtures and clothes; more than three-tenths of 1 part per million is considered excessive for municipal supplies. Iron-containing waters can be treated on a large scale by aeration, such as is done with sprays at New Castle or with trays at Newark, followed by filtration. This process also removes carbon dioxide, which may be objectionable. On a smaller scale, ion-exchange filters can be obtained to remove iron, and a relatively inexpensive chemical (polyphosphate) can be used by householders to prevent the iron from precipitating.

The population and industrialization of Delaware have increased significantly within recent years, but the human and industrial wastes have increased at an even greater pace. Initially, the untreated waste was poured into sewers and ditches, eventually reaching and polluting the streams, the bays, and the ocean. Modern methods of sewage treatment have evolved, using digestion tanks, filter beds, and disinfectants, so that the outflow from some treatment plants is pure enough to drink. Nevertheless, treatment does not reduce the load of dissolved solids; instead, it converts the dissolved solids to a tolerable form. To return to the stream an outflow of the same or better chemical quality as the inflow, demineralizers would have to be used. These are expensive and are not practical for large flows. There is much yet to be done, and pollution abatement will continue to concern our society.

Water is significant to man in Delaware not only for its uses, but also because it is so abundant in some places that the lands are saturated or overflowed during a considerable part of each year. Thus, Delaware experiences many of the wetland problems of other lowlands, such as the Netherlands in Europe. These problems are drainage, shore erosion, and salt-water encroachment.

This synopsis of the development of water supply, with special reference to Delaware, would not be complete without consideration of the manifold uses of water today. The modern farm is absolutely dependent on a sustained adequate water supply for watering stock, washing, cooling, sprinkling, and—even in humid Delaware—for an increasing amount of crop irrigation. The modern home requires water for cooking, bathing, dishwashing, laundering, lawn sprinkling, and fire protection. Modern industry requires many tons of water, used in a variety of ways, for each ton of finished product. For example, ordinarily it takes 80,000 gallons to make 1 ton of fine rag paper, 30,000 to 65,000 gallons to process a ton of finished steel, and more than 1,000 gallons to slaughter and process a hog.

In Delaware, man uses for all purposes (city, industry, and farm) about 40 billion gallons of fresh water a year. This is a significant quantity of water, in terms of present costs, perhaps worth about $6 million. This 40 billion gallons of water is slightly more than 2 percent of the average yearly precipitation.



ENVIRONMENT OF DELAWARE

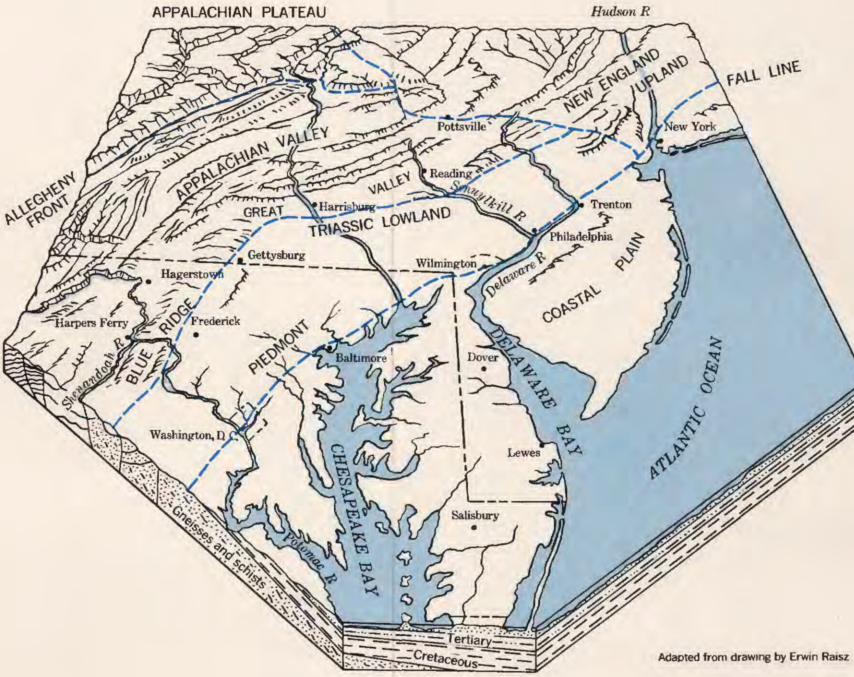
WATER is the most vigorous geologic agent. Erosion by running water has, through countless ages, torn down the mountains and deposited the debris of gravel, sand, and clay in the valleys and in huge aprons, fans, and deltas. Erosion by the pounding sea has undermined the shore and shifted the sediments down the Continental Shelf and Slope. In the northland, glacial ice has plucked huge boulders and ground them to cobbles, pebbles, sands, and—even—rock flour.

These powerful forces have, in ages past, contributed to shaping the landmass of Delaware. The rocky hills of the Piedmont are etched in moderate relief by streams which head in higher land in Pennsylvania and Maryland, descend across the rapids of the Fall Zone to the Coastal Plain, and then flow quietly to the ocean. The Coastal Plain is the upper surface of a huge apron or wedge of sedimentary rock, part of which was formed by deposits of outflowing streams and part by deposits from currents of the ocean.

Thus the topography, the drainage, the rate of infiltration, and the storage of water beneath the land surface have all been influenced by geologic agents. To understand the water problem, we must look at the shape and lay of the land and examine the geologic formations to determine their component rocks and minerals, their grain size, their pores and fractures, and their structural relations, as shown in the regional block diagram (p. 16).

Structure of the Earth

The landmass of Delaware is composed of both an old land and a young land. The old land is highly folded, metamorphosed (rock minerals have changed and become elongated), and intruded with igneous rock (granite, granodiorite, and gabbro—materials once molten that have solidified into fairly large crystals). The old land forms the rolling hills of the Piedmont and underlies the young land beneath the Coastal Plain.

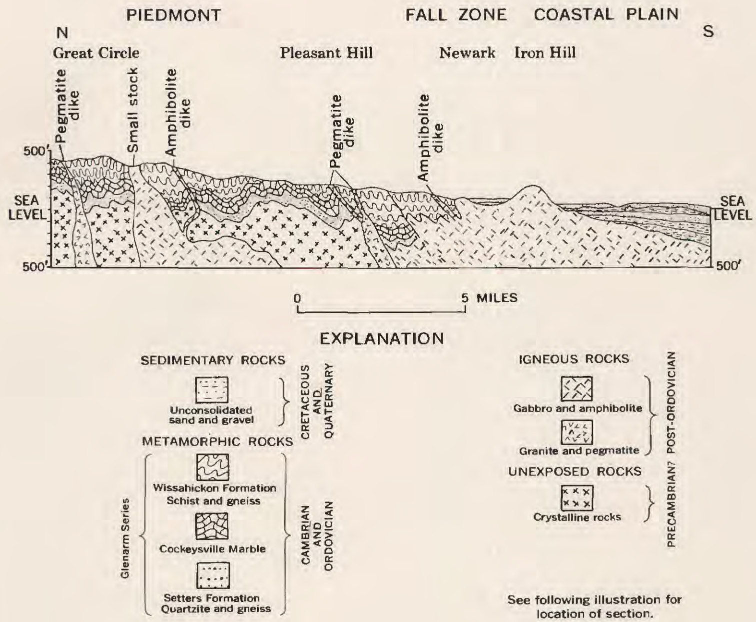


Regional block diagram.

The young land is made up of the relatively soft sediments of the Coastal Plain. These sediments dip, in general, toward the southeast at the rate of a few tens of feet a mile. Water, falling as rain on the outcrop belt, filters into the sands and flows down the slope beneath overlying beds of clay to discharge to wells drilled in the Coastal Plain.

Crystalline Rocks of the Piedmont

The old rocks of the Piedmont in Delaware are a complex of crystalline rocks that were first laid down as a series of sediments. The basal deposit was at first a sand; later, it altered to a sandstone; and, finally, it became completely cemented and altered to a quartzite. A calcium carbonate was deposited on top of the sand. This hardened to a limestone, and during the eventual folding, it recrystallized to a marble. These formations, shown in a geologic section



Geologic section of the Piedmont of Delaware in the Wilmington–New Castle area.

from the Delaware great circle to the Coastal Plain, range from 100 to 200 feet in thickness.

The limestone was covered by a series of clays and sandy clays that were probably more than 5,000 feet thick. These hardened to shales, and, during the eventual folding, were recrystallized, compressed, and sheared into mica schist and feldspar gneiss.

Toward the end of the era of ancient life, mountain-building forces arched and crumpled the sediments into tight folds having a northeastward axial trend. The folds formed the ancestral Appalachian mountains; so, the folding is called the Appalachian revolution. Great changes in climate and in life occurred as a result of the revolution. Many forms of life died out, new forms appeared, and existent forms were modified.

Moreover, the sedimentary rock was baked in internal heat and stewed in internal juices. Huge bodies of molten granite, of granodiorite, and of gabbro became emplaced at the core of the folding. Some of the molten rock forced

Regional configuration of the basement.

its way along fissures, where it solidified into narrow tabular bodies, called dikes, that consist of light-colored pegmatites and dark-colored amphibolites.

The regional configuration of the crystalline rocks beneath the Coastal Plain is shown in the above figure. These rocks are the basement foundation on which the sedimentary rocks are laid. Appreciable quantities of water do not occur in the basement rocks. The surface of the basement slopes southeastward, reaching a depth of almost 8,000 feet below sea level at Fenwick Island in the extreme southeastern corner of the State.

Sedimentary Deposits of the Coastal Plain

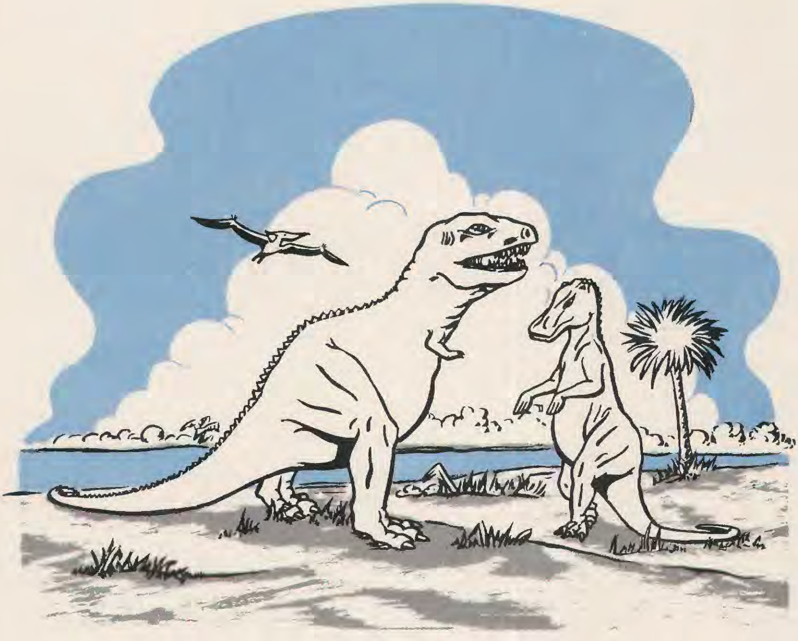
The sediments of the Coastal Plain of Delaware are referable to three great systems of deposition, representing three geologic periods: the Cretaceous, the Tertiary, and the

Quaternary. In Delaware the Cretaceous System is represented by sand, clay, and greensand. The Cretaceous Period saw the climax of the dinosaurs, or "terrible lizards," which dominated the earth during the Mesozoic Era—the era of medieval life. The Tertiary and Quaternary Periods are in the era of recent life, or the Cenozoic Era—known also as the Age of Mammals and the Age of Flowering Plants. The perspective diagram of Delaware and adjacent areas of New Jersey shows the relation of the Cretaceous, Tertiary, and Quaternary rocks to each other, to the crystalline basement, and to the present land surface.

Cretaceous System

The Cretaceous rocks in Delaware consist of two main groups: the nonmarine sediments, laid down as valley deposits by streams, and the marine group, laid down in the sea or in estuaries connected to the sea.

The nonmarine sediments are generally unfossiliferous, except for lignitized wood and some poorly preserved plant remains. They form a series of at least four formations,



Flesh-eating and plant-eating dinosaurs.

whose thickness is more than 5,000 feet in southeastern Delaware, as shown on the structure and thickness map. The sand is chiefly quartz; it is loosely cemented and capable of yielding moderate to large quantities of water. The clay is varicolored—gray, red, blue, and yellow—and is plastic and impermeable. It yields little or no water.

The marine and estuarine deposits of the Cretaceous System consist of dark clay and yellow quartz sand which contain the soft green mineral, glauconite, also called "greensand." Wells in the sand have low to moderate yields.

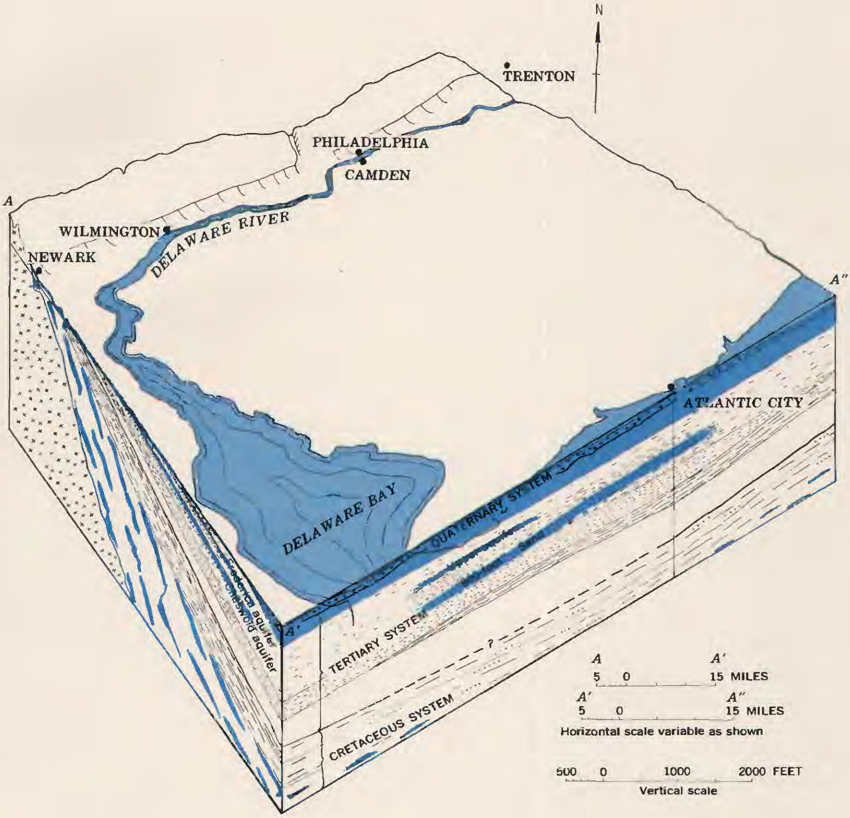
Tertiary System

The Tertiary System in Delaware overlies the Cretaceous System and, in places, is overlain by the Quaternary System. The Tertiary System is dominantly marine, consisting of sand and clay that were laid in the sea under conditions of both shallow and deep water, as shown by the fossil shells and microscopic foraminifers (single-cell animals) and diatoms (siliceous single-cell plants). The sand forms important water-bearing beds in southern New Castle County, Kent County, and Sussex County. The clay protects these beds from salt-water intrusion in the bay and in coastal areas.

A typical artesian system is contained in the Paleocene Series and the Eocene ("Dawn of recent") Series, which form a unit aquifer that has an intake area in southern New Castle County and that then dips progressively below the land surface to depths of more than 1,600 feet at Fenwick Island, the southeastern corner of Delaware. The sand contains usable water that is slightly hard from the intake area to a few miles south of Dover, but the quality of water from the Eocene sands in southern Delaware is doubtful, and a well near Ocean City, Md., is flowing with somewhat salty water.

Quaternary System

The Quaternary, the latest geologic period, represents only the most recent million or half-million years of geologic time. This period is sometimes called the Age of Man because skeletons of manlike beings cannot be traced back to prior periods. The greatest part of the Quaternary Period was an epoch called the Ice Age (Pleistocene), during



EXPLANATION

Water-bearing sands

Gravelly sands (Quaternary) capable of high ground-water yield where sufficiently thick

Sandy silts generally leaky

Clays which do not yield water

Base of Tertiary System is a clayey greensand, with some water-bearing beds

Crystalline rock, both metamorphosed sedimentary rocks and igneous rocks, which yields little or no water

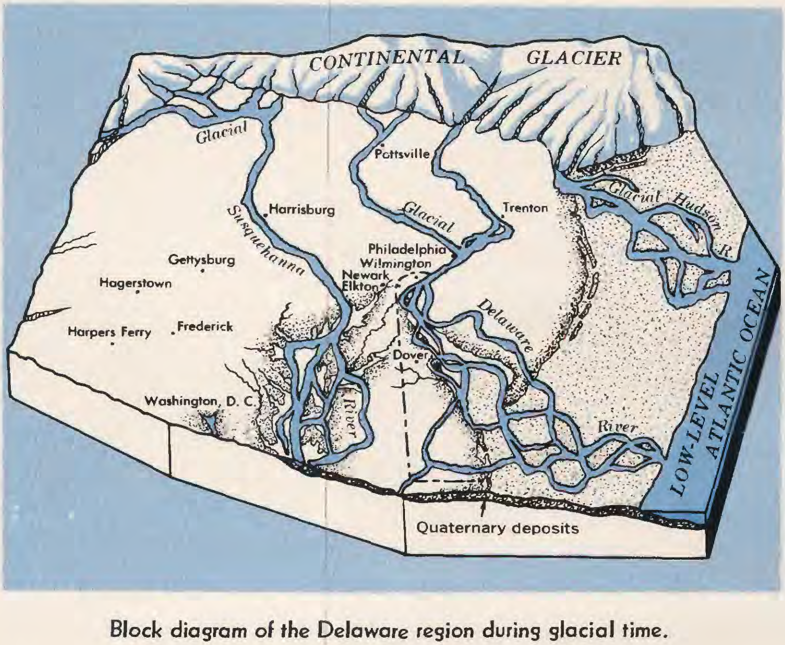
Cretaceous system is a non-marine deposit of lenticular sand and clay. The sands yield moderate to large supplies of ground water

Perspective diagram of the Coastal Plain.

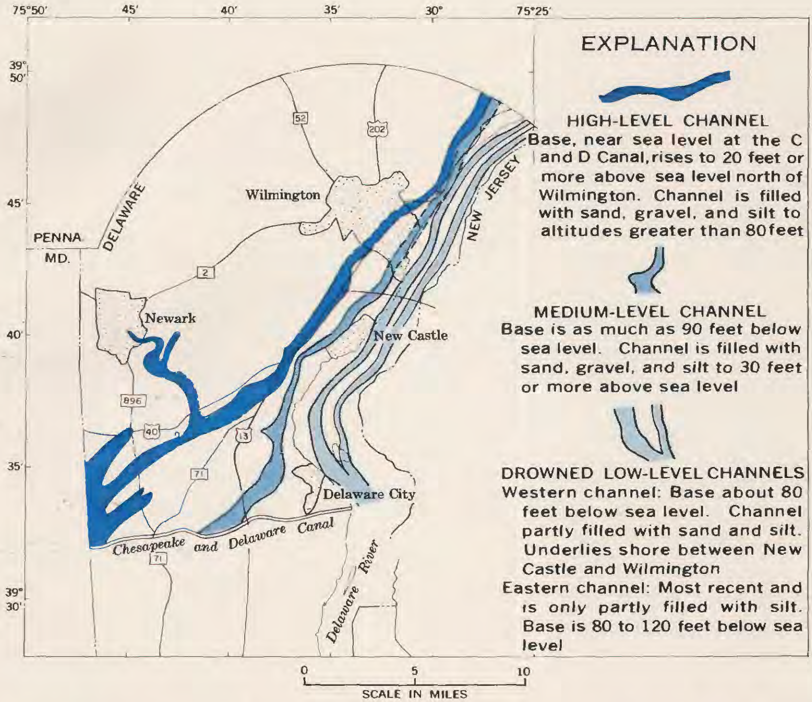
which huge glaciers covered much of the northern part of North America. At least four times, great masses of ice pressed down from Labrador along the east coast, and four times the ice front melted back during an interglacial warm spell. At no time did the ice cover Delaware. The ice halted 50 to 90 miles north of the State, its front extending across Long Island, northern New Jersey, and east-central Pennsylvania, as depicted in the block diagram of the Delaware region during glacial time.

During the advances of the ice, sea level was several hundred feet lower than at present, and there is much evidence suggesting that during at least two of the interglacial warm spells, sea level was 25 to 100 feet higher than at present.

As the ice melted each summer, large volumes of melt water from the ice front swelled rivers to flood stage. These rivers were turbid with sand and rock flour and carried a traction load of gravel. A few boulders and cobbles were rafted on floe ice. Streams which had been carved deep by runoff during the glacial advance were backfilled with the outwash valley trains of glacial debris. This outwash choked



Block diagram of the Delaware region during glacial time.



Buried and drowned channels of the Delaware River in the Coastal Plain of northern Delaware.

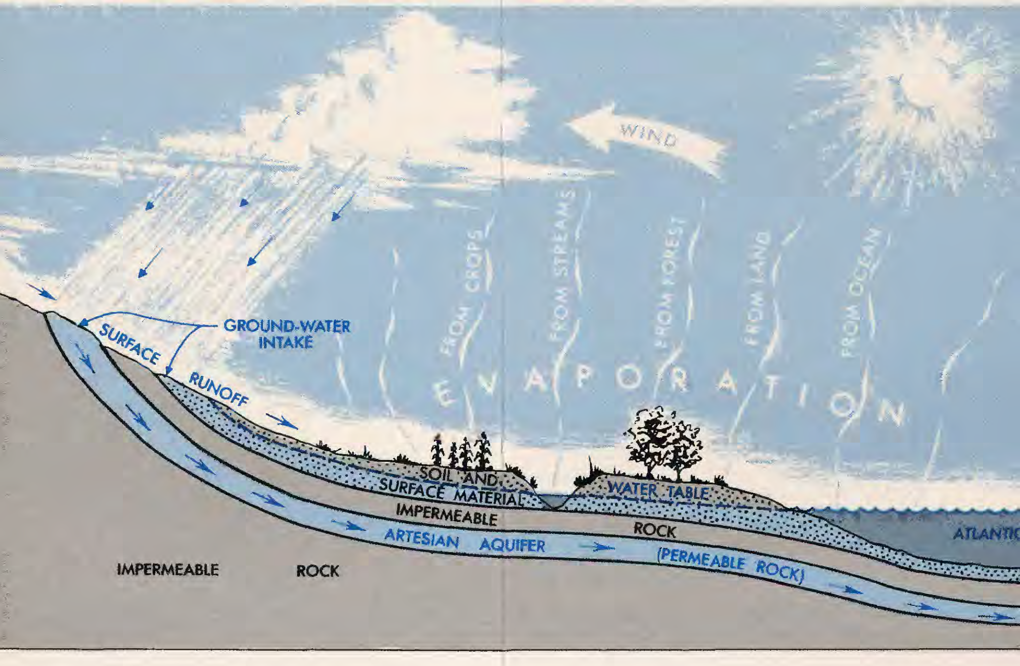
the valleys, until the streams spilled out in braided overflow channels. Four of these buried channels, shown on the map of northern Delaware, indicate early courses of the Delaware River. These buried channels are sources of large supplies of ground water to properly developed wells.

How Water Comes and Goes

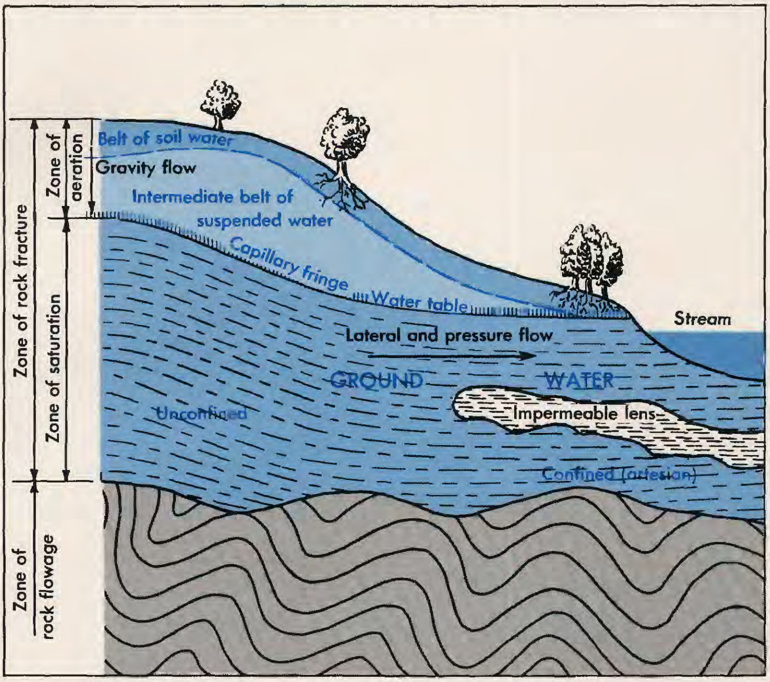
The State of Delaware is served by a tremendous "water-making machine," powered by radiant energy from the sun. The oceans of the world function as a huge teakettle simmering on the solar stove. The vapor they provide is circulated by atmospheric winds, swirled by rotation of the earth, and condensed by the cooling effects of high altitude and high latitude.

Warm moist air from the Gulf of Mexico presses up the Mississippi valley as a warm front and encounters cool to cold air moving down from Canada as a high pressure area. The heavier cool air drives the warm air before it; at the frontal face the moisture condenses as rain, and a storm sweeps across the Appalachian Mountains, over the hills of the Piedmont, and onto the Coastal Plain.

As the rain pelts down upon the land, dry soils soak up the water, and wilting vegetation drinks in the life-restoring moisture. Puddles and pools gather in low spots and overflow in tiny rills. The rills spread to form a sheet flow if the rainfall is intense. The rills merge into rivulets; the rivulets merge into gullies; the gullies merge into creeks; the creeks merge into rivers; and the rivers flow to the sea. Overland runoff is often beautiful, sometimes spectacular, and—in flood proportions—fearsome and awe inspiring. Fortunately for Delaware, floods are rare and confined to small areas, mostly in the Piedmont.



Water circulates endlessly in Delaware.



Belts of ground water.

The soil, saturated by rain, feeds water by infiltration to the openings in the ground below, as shown in the above diagram. The water moves downward by gravity flow through an intermediate belt of suspended water. It reaches the water table, or upper surface of the zone of saturation. There, by devious percolation through the pores between the grains of sand, the water moves in many directions from areas of high pressure to areas of low pressure. In general, the movement is lateral and downhill to points of discharge, such as seeps, upwelling springs, and wells.

Thus, there is a water cycle—sky to ground to ocean to sky. And through this cycle, an average of 1,800 billion gallons of fresh water falls upon the State of Delaware annually. This is our bounty, to do with as we will. Let us make the most of it.

Climate

The climate of Delaware in mid-20th century is humid and temperate; the winters are mild, the temperature rarely reaching zero, and the summers are warm. The growing season is long (185 days, on the average). Rain is plentiful in most years, with no distinct dry season, and averages 44.10 inches annually. The average annual temperature is 55.1°F.

It was not always so in Delaware, even within "recent" times. As recently as 10,000 years ago, the continental ice withdrew from North America, and the modern warm spell set in. The climate has fluctuated to an optimum about 5,000 years ago, when the summer temperatures were about 3°F warmer than at present. Indeed, the last few thousand years have been named the "little ice age" by some geologists because glaciers have reappeared in the Rocky Mountains, the Sierra Nevada, and the Cascade and Olympic Ranges since the climatic optimum.

Is the broad climatic trend one of continued warming, in which meltback of the glaciers on Greenland and Antarctica and a corresponding rise of sea level would drown the Coastal Plain of Delaware (94 percent of the State) to the Fall Line? Or is it one of cooling, in which the eventual return of the continental glacier to North America and a corresponding fall in sea level and enlargement of coastal Delaware would leave our ports and resorts inland? The answers to these questions are still speculation.

Within the period of record, there has never been a drought in Delaware in the strict sense of the word as used in some of our Western States. Nevertheless, in 1858, only 21 inches of precipitation were recorded at Milford, the lowest on record. In 1881, only 29 inches were recorded at Dover. In 1914, only 29.39 inches were recorded at Newark. In 1930, only 24.94 inches were recorded at Millsboro and 28.87 inches at Wilmington. In 1943 precipitation was deficient by about 5 inches, and the deficiency occurred in the summer months. The weatherman said, "A drought prevailed generally from June 19 to September 30 and damaged crops 30 to 50 percent."

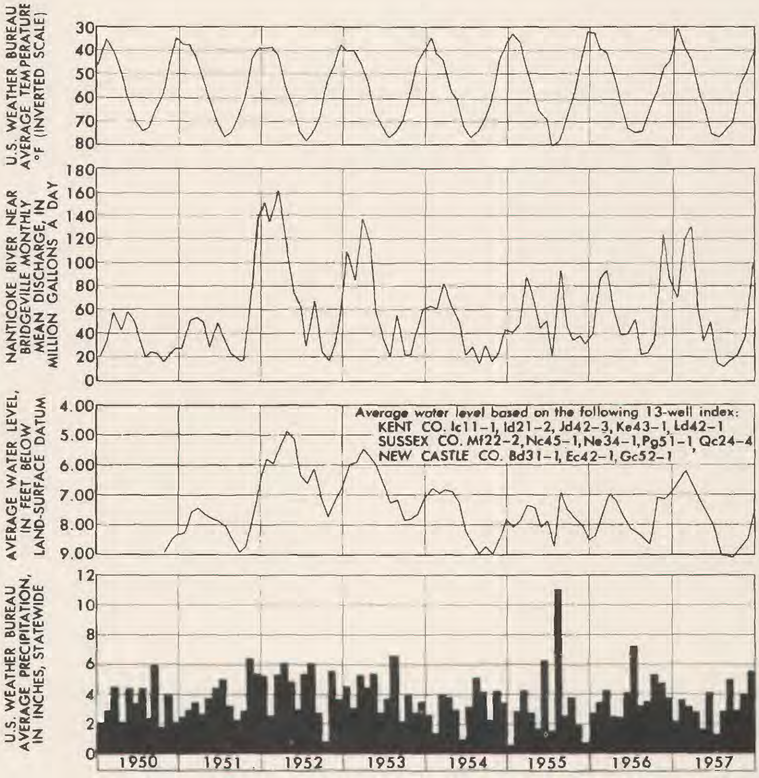
Similarly in 1957, a year of below-normal precipitation (statewide average, 39.04 inches), a deficiency occurred in the summer months. The weatherman said:

During the summer of 1957, the Maryland and Delaware area was gripped by one of the most severe droughts of record. Crop production and farm incomes were reduced sharply . . . the total precipitation for the 4-month period, May through August, averaged less than 67 percent of the long-period mean.

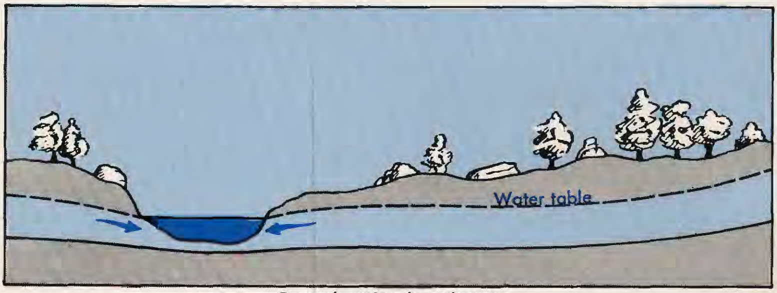
There are years of severe crop restriction, but not of complete crop failure. Many farmers in Delaware now regard dry spells as sufficiently frequent and long to warrant supplemental irrigation in most years.

Streamflow and Ground-Water Levels

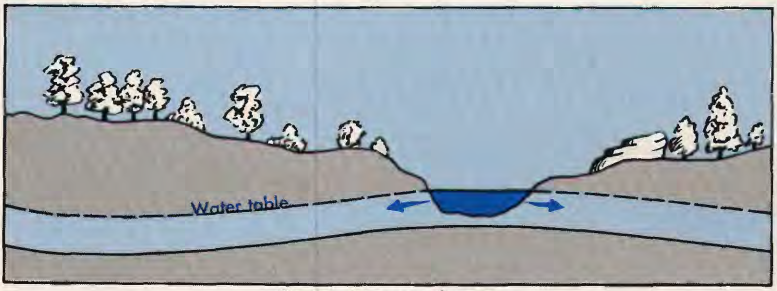
The ground-water hydrograph in the following illustration shows fluctuations which are in sympathy with those shown in the stream hydrograph. During periods of rain, the stream rises rapidly to levels generally above the water table, and some water percolates back into the streambanks, rebuilding bank storage, as shown in the schematic diagram



Graphs showing temperature, precipitation, streamflow, and water levels.



Ground water to stream



Stream to ground water

Seepage from ground water to stream and from stream-to-bank storage.

above. As the rain stops and runoff reduces, the stage of the stream falls, as shown by the steep recession curve, and water stored in the banks seeps back to the stream.

Recharge to the water table in Delaware is direct in winter, when evaporation is at a minimum and transpiration by plants is almost negligible. Therefore, the water that percolates into the ground is not taxed by evapotranspiration and recharges the water table, which reaches the annual high in March or April. Measurements of 13 index wells in the State show an annual high water level between 5.0 and 7.5 feet below land surface.

As temperatures rise after the spring equinox, evaporation from seepage areas increases. The dormant plants revive, sprout, and bud, and place increasing demands upon the stored soil moisture and, in the wet areas, upon the water table itself. A long recession sets in, which is not ended until late summer or early autumn. The lowest water levels recorded at the 13 index wells during the 8-year period range from 7.7 to 9.1 feet below land surface; so, the annual fluctuation is 2 to 3 feet.

Rainfall during the summer is above the monthly average in Delaware, but the demands of the growing plants, of interception by leaves, and of evaporation from all moist surfaces prevent recharge to the water table except during persistent rainstorms. In August 1955, two hurricanes, "Connie" and "Diane," dumped torrential rains upon the State and brought the monthly precipitation to 11.07 inches, or 6.13 inches above the average for August. The average water level in the 13 index wells rose 1.8 feet in response to this abnormal precipitation, and the recession curve was offset. Abnormally dry conditions in the remainder of 1955 caused the water level to continue to decline well into December of that year.

Normally, however, the water levels begin to rise in October, after harvest, as the plants cease their demand for water and as lowering temperatures cause a reduction in evaporation. Ground-water levels are related to temperature; for example, temperatures are highest in July and water levels are lowest 2 months later in September; temperatures are lowest in January and water levels are highest 2 months later in March. The energy of the sun is the "water pump," and it "pumps" most of the water out of the ground in the summer.

Are levels of the unconfined ground water in the shallow reservoir within 100 feet or less of the land surface in Delaware falling? Yes and no. Water levels do not indicate any short-range trend, but 8 years is too short a period of record on which to draw any conclusions. Water-level and streamflow records taken together, however, prove to the field investigator that the ground-water reservoirs still overflow in the winter and spring. This means that the water table, though depleted somewhat in the summer, recovers completely in the winter. There are several artesian ground-water reservoirs for which measurements indicate a local overdraft and lowering of the pressure surface. One of these reservoirs consists of lenticular sands of the nonmarine Cretaceous deposits in the Delaware City area. A decline in four wells northwest of Delaware City ranged from 41 to 50 feet, owing to increased industrial pumpage, which rose from 0.5 mgd (million gallons a day) in 1955 to 4.9 mgd in

1957. A decline of more than 77 feet at Dover occurred in the Cheswold aquifer between 1894 and 1957 owing to increased pumping. Records of wells in the Frederica aquifer indicate a decline of 60 feet in the last 40 years at Milford.

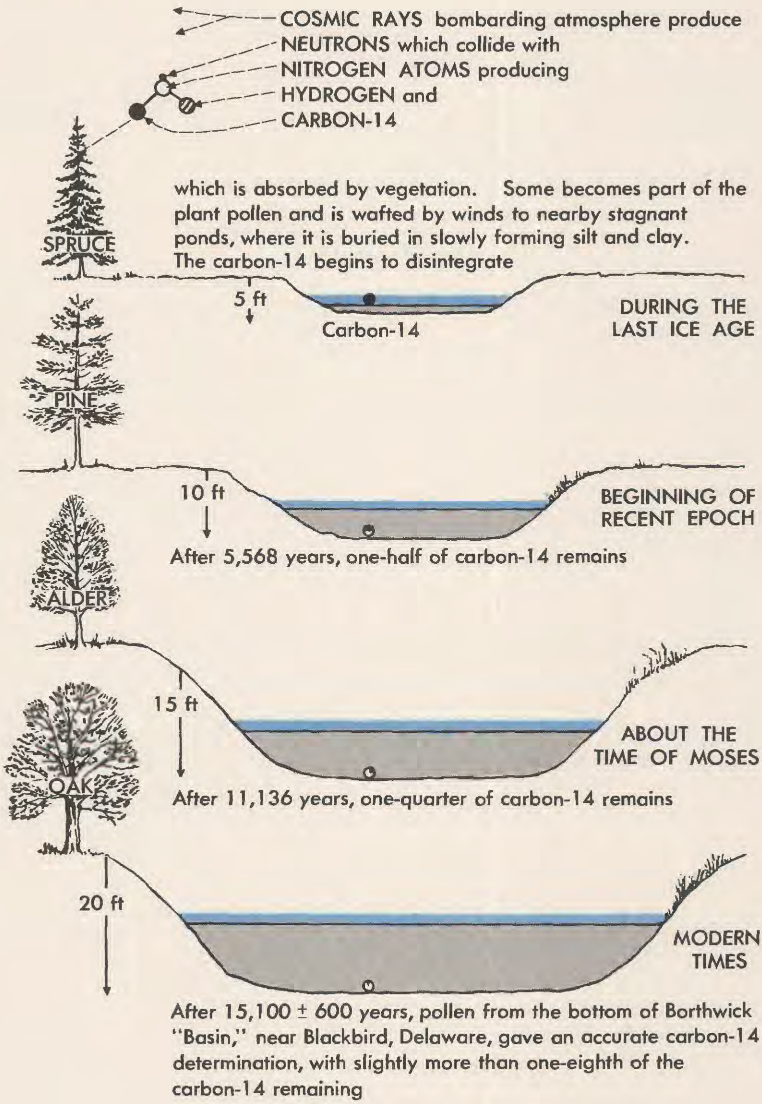
Elsewhere in the State, water levels are sustained, and the water-bearing beds continue to overflow in the spring. To amplify further the answer to the foregoing question: yes, water levels have declined locally, but no, water levels have not fallen significantly in general.

Evapotranspiration

Of an average of 1,800 billion gallons of fresh water that falls upon the State annually, approximately one-third is stream runoff, and the remaining two-thirds, or about 1,200 billion gallons, is evaporated from open water bodies or transpired by plants. Much of the evapotranspiration is useful both to crops and to fields and forests, which are the habitat of wildlife. But an appreciable amount of this water, perhaps as much as 20 percent, is of little or no use. The additional water available for development would be obtained chiefly by curtailing this water loss.

The evaporation and transpiration loss occurs chiefly from many saucer-shaped depressions in the surface of the Coastal Plain. Some of these are small and irregular in shape and have been termed "basins." Others are large and elliptical in shape; a few have long axes, 2,000 feet or more long, oriented northwestward. The large depressions are called "bays" after their resemblance to grander features in the Carolinas and Georgia, known as Carolina bays.

The mode of origin of these bays and basins has been the subject of much conjecture by geologists. A very spectacular hypothesis, applied to the Carolina bays, suggests that the bays were caused by the infall of thousands of meteors in a great meteor shower that supposedly struck the Coastal Plain during the Illinoian stadial or during interglacial time between the Illinoian (next to last) and Wisconsin (last) glaciation. A hypothesis applied to the smaller and less regular basins in New Jersey suggests that they were formed by alternate freezing and thawing out in front of the ice during the last glacial stage. The writers regard the bays and basins as a composite phenomenon; sinkholes formed on the sandy flatlands through removal of material by ground water. The following sketch is a conception illustrating the stages of growth of one of the sinkholes and its progressive filling; the method of age determination is illustrated schematically.



Basin age by radiocarbon and progressive development.

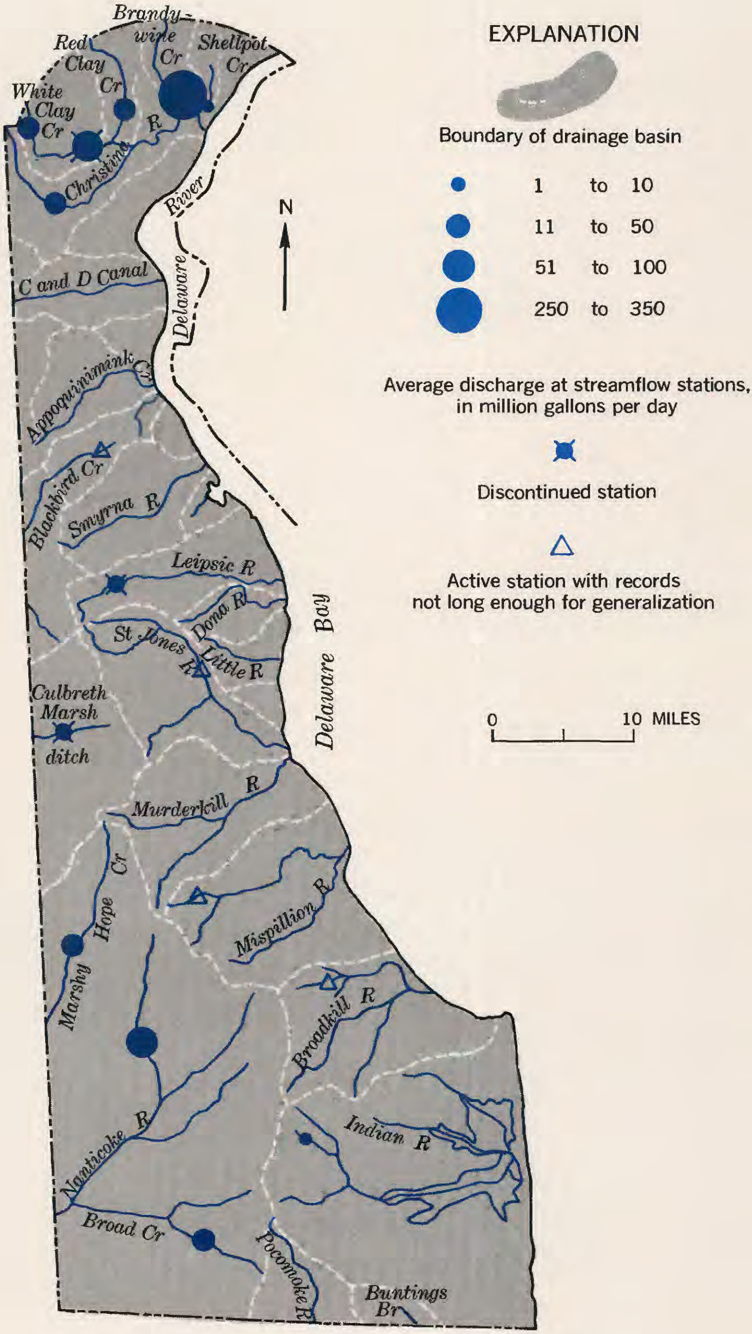
Ten observation wells were established in Savanna bay in Sussex County near Milton. The bottom of this bay covers about one-fifth of a square mile. Calculations based on daily fluctuations of the water table indicated that the average evapotranspiration from this bay in the summer was 1 mgd. The bay functions as a huge well, from which the sun "pumps" water from the water table to the skies. Marsh and swamp plants—including a sphagnum moss, a tickseed sunflower, and the sweetgum—together with many vines and brambles still dominate the larger or deeper of these features. Many of the basins and bays, particularly those in areas where drainage can be effected without difficulty, have been drained and brought into cultivation.

Topography and Drainage

Delaware is in the northeastern part of the Delmarva Peninsula, bounded on the west by Chesapeake Bay and on the east by the Delaware River, its estuary, and the Atlantic Ocean. The State is about 100 miles long and 10 to 35 miles wide. It has a total land and water area of approximately 2,370 square miles. Harvested cropland constitutes 27 percent of this area. The pattern of the streams is shown in the adjacent figure.

The State is composed of two contrasting topographic areas: the Piedmont and the Coastal Plain, separated by the Fall Line. The Fall Line, marked by rapids and falls in stream channels, extends northeastward from Newark to Wilmington. North of this line the Piedmont, constituting 6 percent of the State, is characterized by rolling country with bold hills, moderately deep valleys, and rapidly flowing streams. The principal tributaries of the Christina River draining the Piedmont flow southward. Hilly ridges form the drainage divides between these tributaries and include the highest points in the State. The maximum altitude, about 440 feet above sea level, is located on the divide between Brandywine and Red Clay Creeks at a point near Centerville.

The Coastal Plain contains some gently rolling low hills but in general may be classified as level country. A low

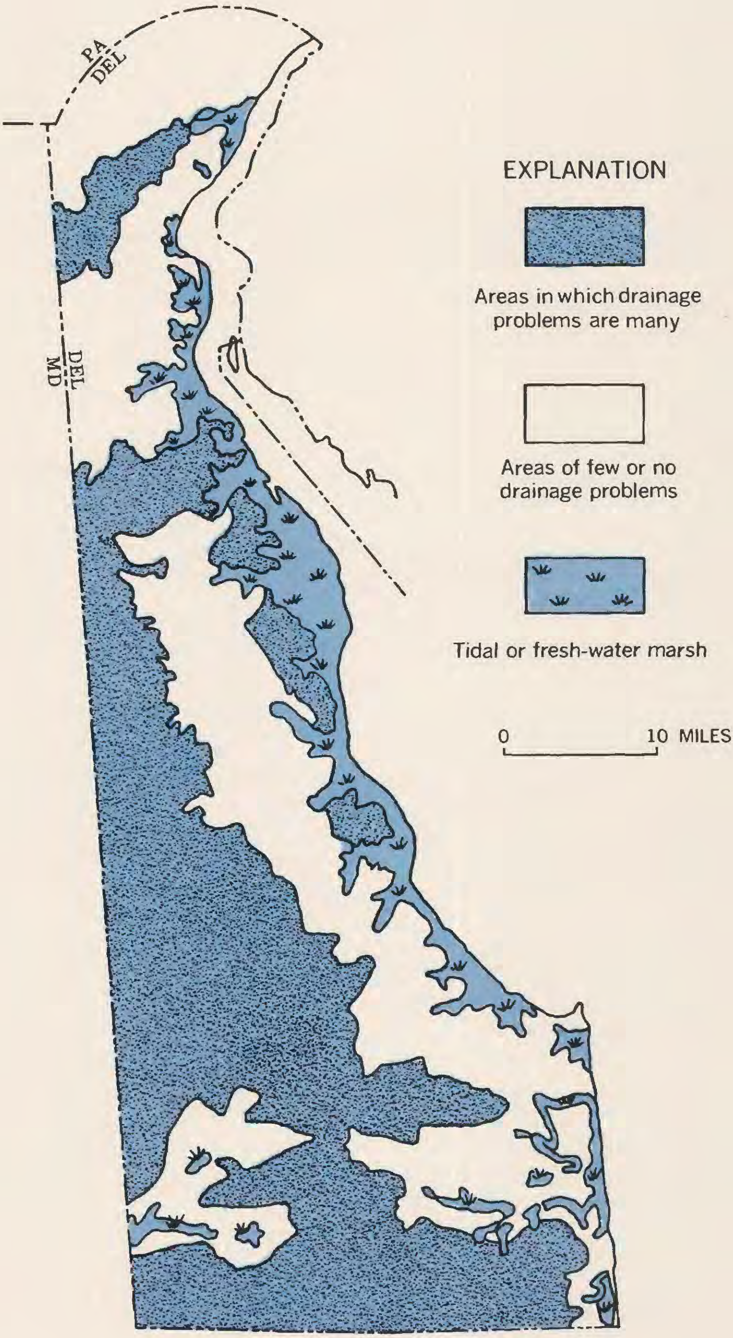


Drainage basins of Delaware and average annual discharge.

ridge extends southward near the western boundary of the State from Glasgow to Harrington, and then runs southeast to Selbyville. This ridge forms the divide between areas draining into Chesapeake Bay and the Delaware River and areas draining into the Atlantic Ocean. Streams in the area have gentle slopes, meandering channels, and sizable areas of swampland. (See fig. 1.)

The streams that flow into the Delaware River and Atlantic Ocean are affected by the tides in their lower reaches. Saline water in the tidal reaches limits water use, as it is not suitable for human consumption, for irrigation of crops, and for many industrial purposes. The streams in the western part of the State that drain to Chesapeake Bay contain fresh water except Nanticoke River below Seaford and Broad Creek below Laurel. Navigation channels maintained on these two streams permit the tides to carry salt water to the upper reach of the dredged channels.

FIGURE 1.—The wetlands of Delaware. The thousand-acre marsh near Port Penn. (Courtesy of the Board of Game and Fish Commissioners.)



Extent of drainage problem areas and tidal marsh.

Natural Quality of the Waters

Water is able to dissolve more substances than any other liquid. For this reason it is unable to remain entirely pure during its circulation from the ocean to the land and back again. Water carries many types of dissolved and suspended matter with it. As rain falls through the atmosphere, it absorbs gases—such as carbon dioxide—and picks up bacteria, dust particles, and spores. If the air is contaminated with industrial and automotive fumes, gases such as sulfur dioxide, ammonia, and carbon monoxide are also absorbed.

In its passage over and through the land, water dissolves minerals from the earth. The amount and nature of the material dissolved varies with the degree of solubility and the duration of contact. Greater quantities of salts are usually dissolved when the waters pass through the ground before reappearing on the surface because of the length of time in which the waters are in contact with the minerals. If the waters pass rapidly over the land, the quantity of dissolved minerals may be relatively small. Generally, one may expect lower concentrations of dissolved minerals during periods of high water than during periods of low water. Thus, the chemical and physical quality of natural waters, ground and surface, depends largely upon the rate of precipitation and upon the geologic and topographic features of the land over which precipitation and runoff occurs. Waters that have percolated through limestone, for example, will be hard; those that have passed through regions of alkalies will be alkaline; and runoff from swamps will be colored and may contain appreciable amounts of iron and organic matter.

Water flowing over the ground may also carry suspended matter, such as silt, decayed organisms, and vegetation. In many river waters, the amount of suspended matter is large; in other waters, the suspended matter may be colloidal and difficult to remove.

Chemical Quality of Surface Waters

All natural waters contain varying amounts of dissolved mineral matter, which is derived from the solution of materials found in the rocks and soils or from the decomposition of organic material in the swamps, marshes, and tidal lowlands. Samples of surface waters from more than 50 sites in Delaware have been chemically analysed since 1955. The streams were sampled above the head of tide, where salinity from the Atlantic Ocean and the Delaware River and Bay does not affect the natural quality of the water. Twelve sites have also been sampled on the the tidal Delaware River and Bay.

Although data on the chemical quality of water in Delaware are limited, the samples indicate that the surface waters, above the confluence of the tides, can be divided into three groups. The first group covers the sites sampled on the Christina River, White Clay Creek, Red Clay Creek, Mill Creek, and Brandywine Creek and on their tributaries. The second group includes those sites sampled below the Christina River, but above and including the St. Jones River. The third group comprises sites sampled below the St. Jones River.

The first group of sites is on the Piedmont Province, which is composed mainly of crystalline and metamorphic rocks. The positively charged constituents in the waters range in concentration as follows:

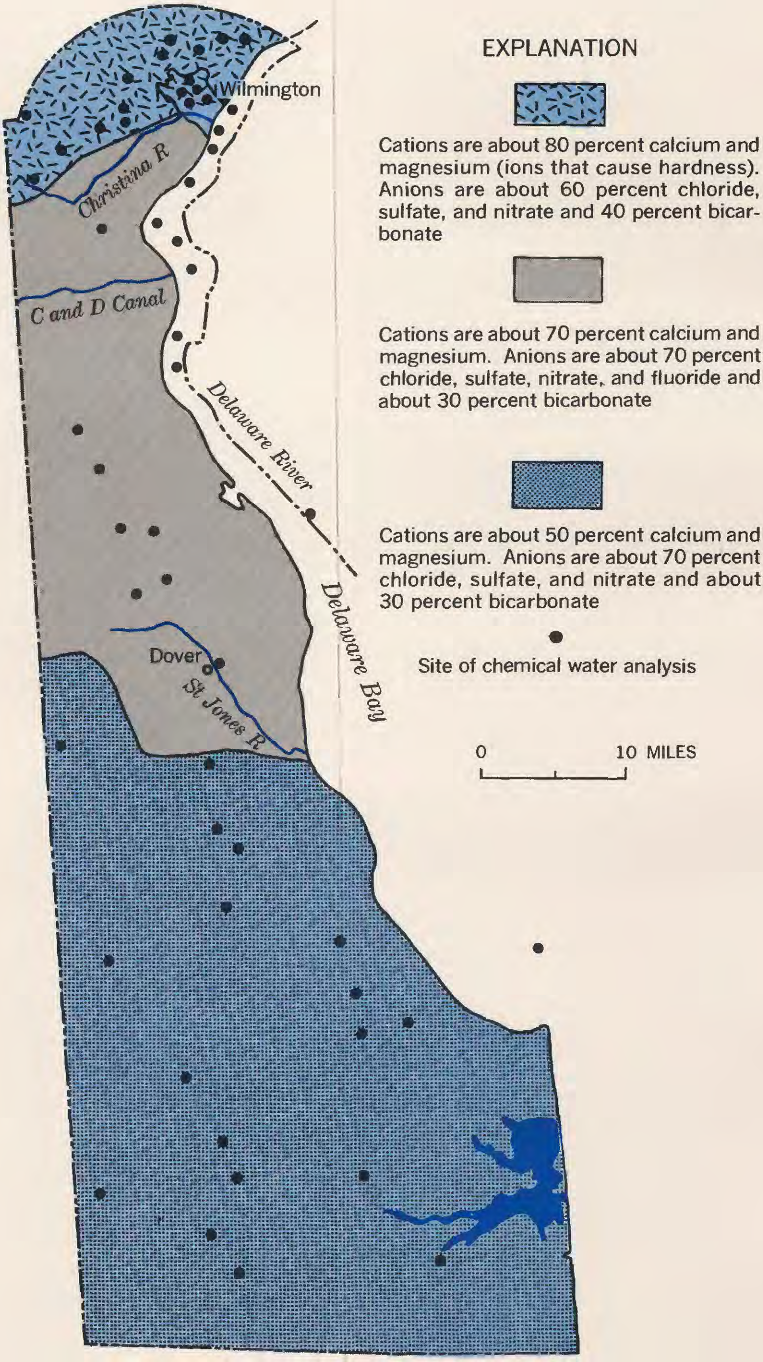
	Percent
Sodium and potassium	10–30
Calcium and magnesium	90–70

The negatively charged particles range in concentration as follows:

	Percent
Bicarbonate	30–50
Chloride, sulfate, nitrate, and fluoride	70–50

The second and third groups of sites are on the Coastal Plain, which is underlain by clay, peat, sand, and gravel. Many of the streams in these two groups are influenced by tides from the Delaware and Chesapeake Bays and the Atlantic Ocean, and there are numerous swamps and marshes. The waters in the second group are characterized by the following concentrations:

	Percent
Sodium and potassium	20–40
Calcium and magnesium	80–60
Bicarbonate	20–40
Chloride, sulfate, nitrate, and fluoride	80–60



Chemical quality of surface waters of Delaware.

The waters of the third group are characterized by the following concentrations:

	Percent
Sodium and potassium	40–60
Calcium and magnesium	60–40
Bicarbonate	20–40
Chloride, sulfate, nitrate, and fluoride	80–60

The foregoing tabulations show that the alkalies (sodium and potassium) increase in concentration southward. Likewise, the strong-acid radicals (sulfate, chloride, and nitrate) increase southward. Both these increases reflect the increasing influence of the sea, which has very high concentrations of these constituents. Ocean spray blown in by storms plus residual salts left in the sedimentary units when they were deposited may account for these increases. The dissolved solids in the fresh surface waters in the State range from 30 to 130 ppm (parts per million—a unit weight of a dissolved solid in a million unit weights of water).

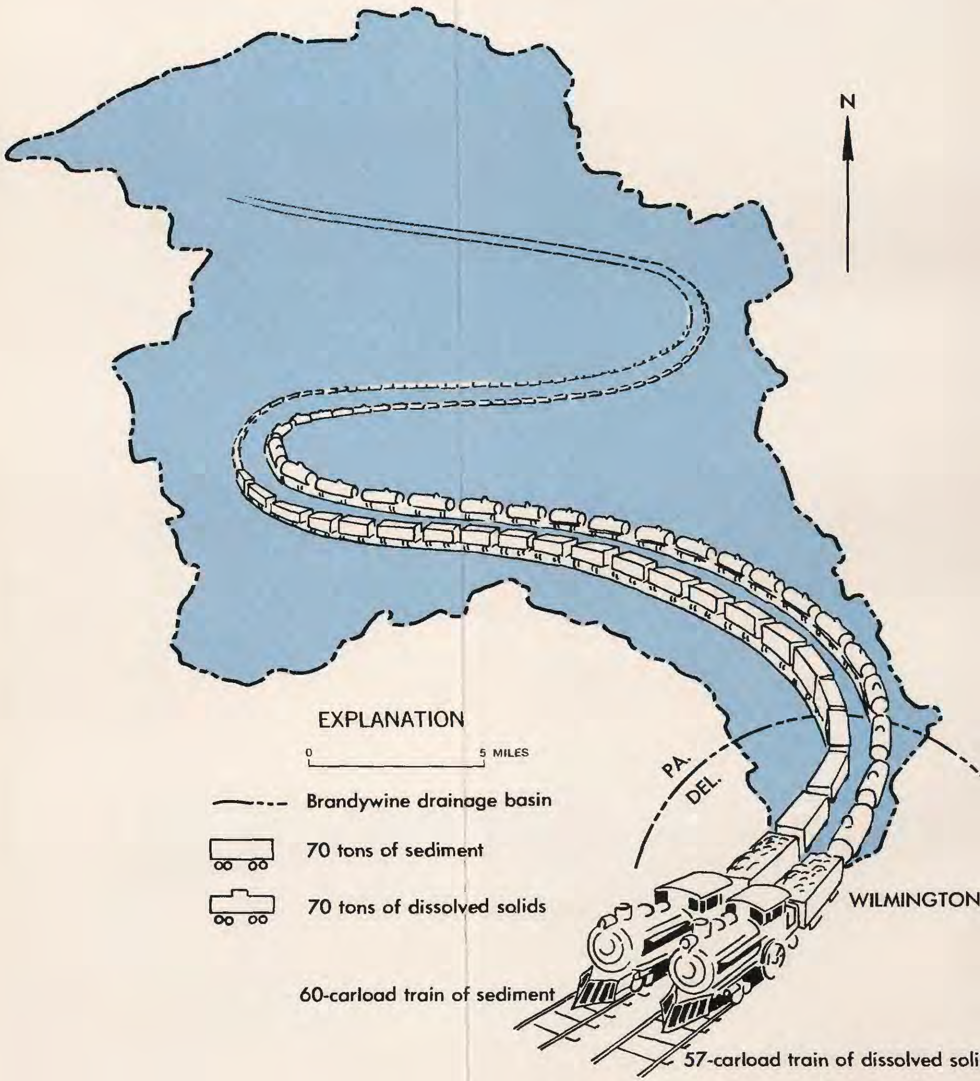
Physical Quality of Surface Waters

The U.S. Geological Survey, in cooperation with the State of Delaware and the Brandywine Valley Association, is investigating the physical quality of Brandywine Creek. Measurements of rainfall, runoff, and sediment are being made in the drainage basin in order to study the suspended-sediment discharge at Wilmington and to thereby ascertain the trend of sediment yield.

Sediment yield is related to erosion from the uplands and to transportation in the channels. The concentration of suspended sediment depends on the season of the year, the source of runoff, and the intensity and magnitude of the storms. Related factors include vegetation, soil conditions, antecedent moisture, temperature, raindrop size and intensity, wind velocity during the storm, and the hydraulic characteristics of the stream channels.

The monthly sediment load of the Brandywine River at Wilmington averages 4,200 tons, whereas the monthly dissolved solids average about 4,000 tons. (Shown graphically as freight-car trains on p. 40.) Year by year, century by century, quantities similar to these have been discharging from the Piedmont drainage basins of Delaware. They represent both erosion and renewal of the soil.

The Brandywine Valley Association was formed in 1946 to promote better land-use practices, soil conservation, and pollution abatement. Between the periods 1947–51 and 1952–55 there was a decrease of approximately 38 percent



Average monthly sediment loads of Brandywine River.

in sediment yield from Brandywine Creek. Conservation practices may have been responsible for the decrease.

Quality of Ground Waters

Natural ground waters are almost universally free of bacteria, because the filtering action of the earth particles usually removes soil bacteria within a few feet of the soil zone. The chemical quality of the ground water in Delaware is discussed in the section, "Twelve ground-water reservoirs," in which each reservoir is described separately, and the problem of salt-water intrusion into the coastal aquifers is discussed in the last subsection under "Estuarine and marine conditions."

For most of the State the shallow ground waters are relatively low in dissolved solids, soft or only moderately hard, neutral or slightly acid in pH, and may contain small but troublesome amounts of iron. They are suitable for most purposes with little or no treatment except as indicated in the sections cited. The quality of the deeper ground waters, below depths of 1,000 feet, is mostly unknown but is more likely to be high in dissolved solids and usable only for certain purposes. The deeper waters will be at least 10°F warmer than the shallow ground waters, which average about 56°F.

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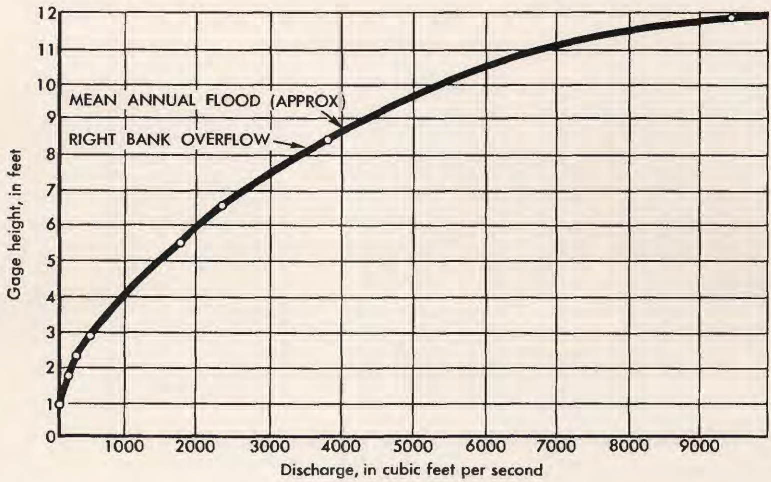
STREAMFLOW

THERE are 13 active gaging stations in Delaware, an adequate number considering the drainage area of the State. None of these stations were operated prior to 1943. Three other stations shown on the drainage-basin map are no longer active but were operated long enough to provide usable data. Low flows are measured on 20 other streams throughout the State, and flood peaks on 5 streams. Correlation of the low flow and flood flow with data from the more complete station records provides a broader knowledge of the water resources.

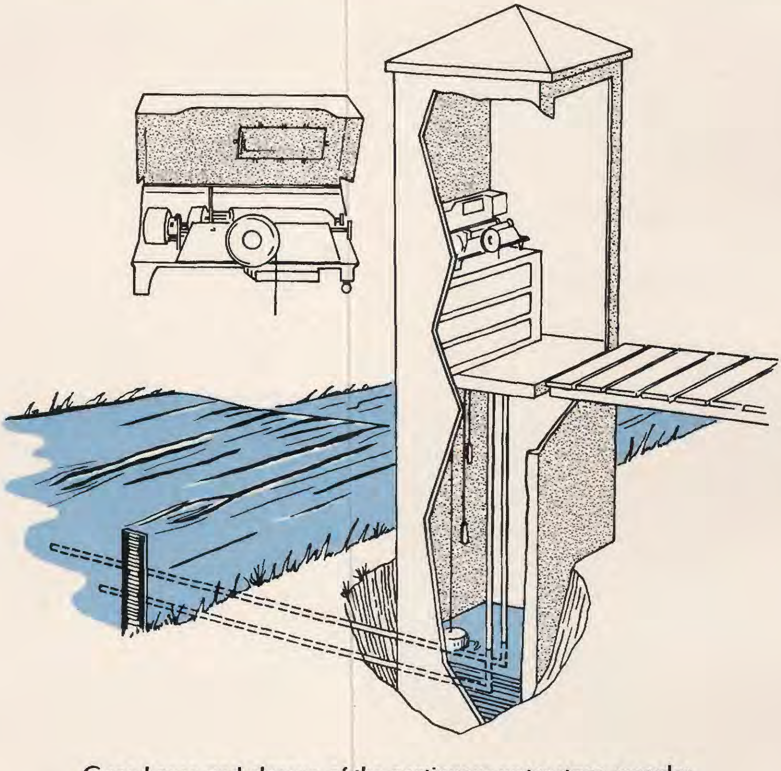
The accompanying sketches illustrate the process of stream gaging. The engineer, in waders, is gaging a stream with a current meter, shown in closeup. The cup vanes rotate and record the velocity of the stream as a function of revolutions per minute. By gaging the streams during high, medium, and low stages, the engineer constructs a rating curve, shown in the second figure, on the following page. A water-stage recorder, placed in a shelter house, as shown in the third sketch, makes a continuous record of the height of the stream. From the hydrograph thus obtained, the gage height is read against the rating curve to determine the rate of flow for each moment of record.

Streamflow varies widely from day to day, month to month, and year to year. The monthly average flow of

Engineer measuring discharge of stream and closeup of his current meter.



The rating curve is based on discharge measurements made at gaging station. Streamflow can be read from the rating curve for any gage height obtained from the continuous water-stage recorder.



Gage house and closeup of the continuous water-stage recorder.

Nanticoke River near Bridgeville (fig. 2) for 1950 to 1957, in million gallons per day, is shown on the hydrograph illustrated on page 27. Although the graph illustrates the general variation in flow, it does not reveal the great extremes that have occurred. Records collected at this point since April 1943 show that the average flow for the month of September 1943 was only 6.53 mgd; however, records for nearby streams in Maryland indicate that the flow was even less during the 1930 drought. The maximum monthly average flow during the period of record was 193 mgd in June 1958. In exaggerated contrast, the maximum flood peak for the period of record was seven times as great, reaching 1,490 mgd on August 26, 1958. Both of these maximums have undoubtedly been exceeded many times in previous years of abnormal streamflow.

The uneven distribution of streamflow results in deficient water supplies during periods of drought and excessive flows

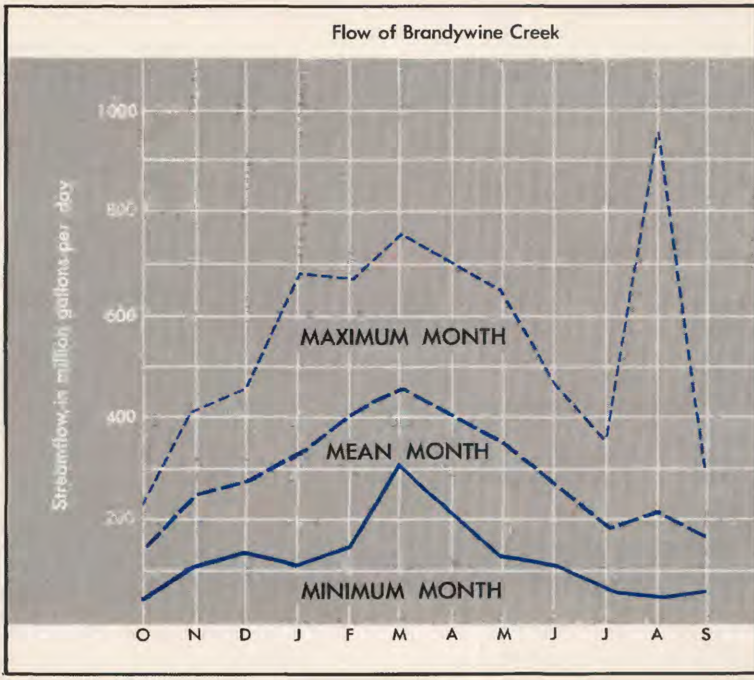
FIGURE 2.—Streams of Delaware. A, Brandywine Creek near flood stage in Wilmington, August 19, 1955; Hurricane Diane was here August 18, and Hurricane Connie was here August 12–13. B, Gaging station on Red Clay Creek, with concrete control across stream. C, Gaging station on the Nanticoke River near Bridgeville. Submerged weir in foreground; gagehouse and staff in background.

that are lost to the ocean during periods of heavy rainfall. This undesirable condition may be remedied, within limits, by providing reservoirs to store storm runoff for release and use as the water is needed. It is not economically feasible to store all excess water; so, the possibilities for development are numerous, depending upon the availability of suitable reservoir sites, the various purposes for which the water is stored, and the rate of use. Designs of dams, bridges, culverts, and other hydraulic structures are dependent upon records of streamflow. It is particularly important to know the extreme flows, both high and low, that may be expected during the useful life of a structure. Many years of continuous records are needed to supply the data. The records collected to date in Delaware do not include the worst known drought or the more disastrous flood periods. Therefore, allowance must be made for these more extreme hydrologic events whose limits are not indicated on the available records.

Magnitude of Surface Waters

The annual average discharge at the gaging stations in the State varies greatly depending on the drainage area above each gage. However, if the discharge is converted to runoff per square mile, the data indicate only a moderate variation in yield. The average for all the gaged streams is approximately 0.8 mgd per sq mi of drainage area. Brandywine Creek at Wilmington (fig. 2) has the greatest yield, 0.94 mgd per sq mi. The relatively short records for the gaging stations do not include data for known droughts and floods; therefore, the averages may change when the stations have been operated for longer periods. Nevertheless, if 0.8 mgd per sq mi is taken as being a representative value for the land area of Delaware, which encompasses 1,965 square miles, then the average daily discharge is roughly 1.5 billion gallons. This is a lot of water, enough runoff in 1 day to last the city of Wilmington 2 months.

The growing population of the State, increase in per capita domestic use of water, expanding industries, and demands for water for supplemental irrigation have resulted in tem-



Average and extreme monthly flows of Brandywine Creek.

porary shortages of water in some areas. This situation can be alleviated by providing for storage of water to supplement the streamflow during drought periods.

Hoopes Reservoir was constructed to store water for use by the city of Wilmington. Other reservoirs may be provided on many of the streams as the need for water justifies the cost of construction. Frequently, it is possible to utilize a dam and reservoir for water supply, flood control, recreation, propagation of fish and wildlife, irrigation, pollution control, and power development.

Floods

Floods occur in the United States every year. Millions of dollars in flood damage is suffered and not infrequently lives are lost. Residents may be forced to leave their homes; industrial plants, to suspend operations. Some homes are carried away by floodwaters and others are partially submerged. Thousands of dollars are spent to evacuate people from an area so afflicted and to rehabilitate the homes and factories after the flood subsides. These floods are spectacular and receive much publicity in newspapers and on radio and television.

Delaware is usually not plagued with this type of flood partly because of the topography of the State and partly because of the foresight of planners, who did not permit development on the flood plains of streams. On March 5 and 6, 1920, the city of Wilmington experienced a flood of Brandywine Creek (see fig. 2); damage was in excess of $100,000. Six blocks were flooded to the second story in the area beyond the 11th Street bridge. About 500 people abandoned their homes and took shelter in police and fire stations. All bridges in the area were imperiled. Many boats were torn from their moorings, dashed against the bridges, and demolished. A 50-mph gale accompanied by heavy rains knocked out power and telephone lines. Roadbeds were threatened by high water, and rail service was interrupted.

Streams in the Piedmont of northern Delaware, where slopes are relatively steep, have channels of adequate size to carry most floods. In the Coastal Plain the flatness of the country slows the rate of concentration of water in the streams and allows them to carry the excess water downstream without reaching extremely high stages. The low brushy banks, however, are frequently overtopped, and the water spreads out over agricultural land, causing extensive crop damage. This type of flooding is not spectacular, and because the damage it causes is not limited to relatively small areas—such as industrial and population complexes—the usual flood-control measures may not be economically feasible. Additional damage to secondary roads and their drainage structures is not unusual.

CONTAMINATION AND POLLUTION

WATER, as with all things readily available for use by man, is often taken for granted. Prior to colonization, water from the area that is now the State of Delaware was used by the Indians. Human use of water for agricultural, domestic, and other needs increased after the Dutch founded Zwaanendael (now the city of Lewes) in 1631. The use of water has increased continuously with the growth of population, farms, and industries and has been accompanied by an ever increasing amount of contaminants (chemical adulterants) and pollutants (organic wastes) discharged into the streams and lakes within the State.

As contaminants and pollutants increase, the problems encountered by the users along the watercourses also increase. Treatment to remove undesirable impurities, before the water is used by industries, may be costly. Some pollutants contribute to the rotting of piers, pilings, and boat hulls and also weaken concrete structures. Pollution may be harmful to fish in several ways: by reducing the oxygen concentration of the water, by clogging the gills of immature fish, by covering and smothering the spawn with silt or poisons, or by causing changes in the aquatic life on which the fish subsist. Oysters and clams, grown in polluted waters, may harbor pathogenic organisms; moreover, various organisms causing intestinal diseases are probably waterborne.

The dairy industry is also affected, for polluted waters can infect entire herds of cattle with parasites, which endanger the lives of both the animals and the consumer. The growth of crops may be stunted if irrigation waters are polluted with excesses of certain chemical constituents, such as sodium chloride and acids.

Streams have natural self-purifying powers. Briefly stated, the following is the history of a stream downstream from a source of pollution:

The water becomes turbid. Aquatic vegetation dies for lack of sunlight. Dissolved oxygen decreases. Scavenging organisms increase. Some sewage settles to form sludge deposits. As flow proceeds downstream, the oxygen may be completely used up. If no additional pollution occurs downstream, the oxygen demand of the decomposing sewage is gradually matched by the rate of oxygen absorption from the air. Downstream from here, the flow improves in quality. Finally, at some point farther down, all wastes are oxidized, and the stream has almost regained its natural condition.

Self-purification of streams is a slow process that requires much time and long stream travel. It is significant that, even though the sewage solids have been removed by natural action, the dissolved-solids load of the stream is increased.

Categories of Quality

Contaminants and pollutants of the natural waters of the State can be classified under five categories of quality which are studied: chemical, physical, bacteriological, biological, and radiochemical quality. Today, almost any water can be treated by specific methods to produce water of desired quality, but cost determines the extent to which treatment is practicable.

A study of the chemical quality of water provides a basis for determining the type of treatment necessary to make the water suitable for use. Samples are collected at established surface- and ground-water sites in accordance with a plan. Determinations are made of all or some of the following: dissolved solids, phenols, cyanides, color, pH, temperature, specific conductance, silica, iron, copper, chromium, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, chloride, fluoride, nitrate, and hardness. Other important minor elements are determined as required.

In addition to the dissolved materials, streams carry suspended materials, such as dust, bacteria, spores of fungi, organic residues of animals and plants, sediment and silt, iron oxides, various types of trade wastes, municipal sewage, and fibers.

The concentration of the sediment, its total quantity, and the distribution of particle size are commonly determined. This information is useful in studies of erosion, in the study of sedimentation in stream channels and reservoirs, and in planning treatment of the water for industrial or municipal use.

Biological investigations of polluted streams use living organisms, plants and animals, as indicators of stream conditions. The biologist investigates the types and number of plants and animals in a stream, and furnishes related chemical data, such as dissolved oxygen and biochemical oxygen demand—the quantity of oxygen used in the biochemical oxidation of organic matter within a specified time and at a specified temperature.

Bacteriological and sanitary surveys are conducted using a roughly quantitative measure of the density of the coliform group of bacteria in a given sample of water as an indicator of pollution. Additional tests indicating bacteriological pollution are a bacterial count on standard agar culture medium at normal body temperature (37°C) and a 5-day biochemical-oxygen-demand determination. Other routine determinations made on the samples are temperature, turbidity, alkalinity, and chloride content.

The fifth category of water quality mentioned above, radiochemical quality, is a potential source of stream pollution. Several organizations have instituted preliminary studies of the radiation levels in the vicinity of the State of Delaware. Among these studies are the Radiation Measurement Program of the Delaware Water Pollution Commission, the Radioactivity Background Monitoring Survey of the U.S. Public Health Service, and a study by the U.S. Geological Survey.

Background counts have been made on artesian water from the middle aquifer of the nonmarine Cretaceous formations at New Castle, from the Cheswold aquifer at Dover, and from the Frederica aquifer at Milford. Radiation levels are very low. In the event of extensive fallout, surface-water supplies may temporarily be contaminated, and reliance would be placed on the artesian waters.

Pollution Abatement

To abate the nuisance of polluted waters, the legislature passed the Delaware Water Pollution Control Act in 1949, creating the Delaware Water Pollution Commission. Many investigations have been reported. The commission has made recommendations for treatment, which have been followed by cities, towns, industries, and private persons in the State. Substantial progress toward the attainment of pure water has been recorded, but with rising quantities of waste, increasing vigilance must be maintained.

Water Purification

Most public drinking supplies in Delaware are drawn from ground-water sources (wells and springs), but some are taken from surface sources. The city of Wilmington, for example, draws its entire public water supply from the Brandywine Creek, and the community of Claymont purchases part of its water supply from the Chester, Pa., Municipal Authority, whose source is Octoraro Creek in Pennsylvania.

Water purification is achieved in diverse ways, depending on the qualitative and quantitative requirements and on the source of the water. Purification of the public water has, however, become a necessity. Filtration and chlorination have been helpful in bringing under control systemic diseases such as typhoid fever, paratyphoid fever, amoebic and bacillary dysentery, cholera, gastroenteritis, and infectious hepatitis. Water purification together with other treatment may also remove suspended matter, iron, manganese, algae, acidity, and hardness.

At one stage of purification the water, either raw or finished, may be stored in a reservoir. In these reservoirs pathogenic organisms, bacteria derived from the excreta of diseased animals or other sources and capable of infecting a new victim, tend to die out owing to the unfavorable food supplies and competitive life. This process is known as bacterial self-purification. The color or aqueous extract of the soluble material contained in the decaying vegetation and swamp material is bleached somewhat by the sun while in storage. Iron, an essential constituent in this organic color extract, undergoes oxidation and with other finely divided suspended matter settles to the bottom of the reservoir.

Accompanying these advantages of reservoir storage are disadvantages, such as disagreeable tastes and odors introduced by the increased growth of plant and animal life; however, this condition can be controlled in a properly operated reservoir. Most algae which flourish in reservoirs are controlled with the addition of chloramine (chlorine and ammonia) and copper sulfate, used separately or together. Potassium permanganate is also used as an algacide.

The Wilmington Water Department operates the Porter and Brandywine Filter Plants. Raw water entering the Porter Plant, which supplies two-thirds of the water of the city, is treated as follows: addition of lime to raise the pH, prechlorination to kill bacteria, addition of alum to induce coagulation, addition of activated carbon to remove undesirable odor and taste, rapid-sand filtration removing the carbon and turbidity, a second addition of lime to adjust pH, postchlorination to protect against bacteria in the distribution system, and fluoridation to inhibit tooth decay. A similar sequence is followed at the Brandywine Plant. The following tables show the chemical character of the raw and treated water of the city of Wilmington. Chemically, the difference is slight; the significant difference is in the purity: the finished water is clear and has no bacteria.

Water quality of the city of Wilmington

[Analyses by Geological Survey, U.S. Department of the Interior. Results in parts per million except as indicated]

	Brandywine Creek raw water	City tap finished water
Date of collection	5-31-50	4-25-51
Silica (SiO_2)	12	12
Iron (Fe)	.08	.10
Calcium (Ca)	11	12
Magnesium (Mg)	4.5	4.4
Sodium (Na)	6.7	5.4
Potassium (K)	....	1.0
Bicarbonate (HCO_3)	38	27
Carbonate (CO_3)	0	0
Sulfate (SO_4)	17	28
Chloride (Cl)	4.8	6.0
Fluoride (F)	.1	.0
Nitrate (NO_3)	5.7	3.9
Dissolved solids (residue on evaporation at 180°C)	89	89
Hardness as $CaCO_3$	46	48
Noncarbonate hardness as $CaCO_3$	15	26
Specific conductance...micromhos at 25°C	131	137
pH	6.8	7.1
Color	5	3
Temperature ...°F	64	60

Regular determinations at treatment plant, 1950

	Alkalinity as $CaCO_3$ (ppm)			pH			Hardness as $CaCO_3$ (ppm)			Turbidity		
	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min
Raw water.	35	49	10	7. 2	8. 4	6. 9	....	....	....	40	800	8
Finished water....	27	40	3	6. 5	6. 9	5. 3	52	62	40	0	0	0

The Wilmington Suburban Water Corp., which supplies the communities of Bellefonte, Bellevue, Claymont, Gwinhurst, Holly Oak, Silverside, and others in New Castle County, obtains about 25 percent of its water from natural springs. This water is treated as follows: Prechlorination, coagulation with alum, sedimentation, rapid sand filtration, postchlorination, and adjustment of pH with lime. The remainder of the supply is obtained mostly from the Delaware Water Corp. and a small amount from the Chester, Pa., Municipal Authority.

The cities of Dover, Lewes, Milford, New Castle, and Seaford and the municipality of Newark draw their public water supplies from wells. These waters are treated in several ways—including aeration, chlorination, coagulation with lime, and adjustment of the pH with lime—before they are released to the consumers.

Sewage Treatment

Because streams provide the easiest and most economical means of waste disposal, most cities discharge their human wastes into the nearest river or stream available. This same stream may be used by others downstream for drinking water and to supply water for industrial, agricultural, and recreational needs. As stated previously, streams have an amazing ability to treat wastes and thus purify themselves. When the pollution load becomes too heavy, however, it is necessary to give nature a helping hand. In order to make the river safe for use by others, the wastes of a city should be treated before they are discharged into the river.

Municipal sewage treatment includes the removal of suspended solids—both organic and inorganic—to a reasonable extent, conversion of the remaining organic material into stable forms that will not decompose further and thereby produce odors, and the reduction of the pathogenic bacteria count of the effluent. The degree of treatment depends on the character of the waste itself, the number and kind of future users of the stream, and the upstream discharge of wastes. Most sewage treatment in Delaware, including that used in Wilmington, is of the primary type, which allows the suspended solids in the sewage to settle out in large open tanks and discharges the relatively clear remaining liquid into the streams.

Development of the Wilmington-New Castle County trunk sewerage system in 1954 gave northern Delaware a sanitary district of first importance in the State. The Director of the Delaware Water Pollution Commission stated before a U.S. congressional committee that of the 51 incorporated towns in the State, 34 have primary treatment provisions, 7 are under construction, and 5 are in the planning stage. Other communities employ streams, cesspools, septic tanks, and privies to dispose of their sewage.

Industrial Waste Disposal

Satisfactory answers to industrial-waste problems usually involve chemical-engineering principles rather than sanitary and biological processes because most industrial wastes do not contain disease-producing bacteria. Occasionally in controlling waste disposal, a useful byproduct, hitherto escaping, is recovered. More often, however, the control of pollution is necessarily a part of the cost of production which an industry must bear as a good member of the community.

The Delaware Water Pollution Commission (1964) reported that of 540 industries within the State 137 (25 percent) are considered to be wet operations, which discharge a liquid process waste. Of these wet operations, about 23 discharge their wastes into municipal sewage systems, where the wastes are treated. Treatment within the plant is provided by 114 of the industries.

Water used for cooling is not normally polluted, but unless the temperature is lowered to normal before it is returned to the stream, the heated water may be disastrous to aquatic life. Wastes from the processing of 2,400 cans (20-ounce size) of beets, corn, peas, squash, spinach, succotash, and tomatoes would produce a degree of pollution comparable to that of the daily sewage of 800 persons. Canneries and food processing plants remove solid wastes by passing the effluents through screens.

In the manufacturing of steel, the steel is given a bath in water to which acid has been added. After the strength of the acid is reduced to a certain point by use, the pickling liquor is disposed of as waste.

Pollutants entering streams from paper and pulp mills include strong acids, caustic solutions, chlorine used in bleaching, inks from the de-inking of used paper, wastes containing filler, and starch. Treatment includes (1) discharge of the highly colored waste into lagoons to allow sedimentation, oxidation, and fermentation or (2) chemical treatment.

Textile industries must remove solids, greases and oils, and dyes and other chemicals. Refineries separate the oil wastes by flotation and the sludges by sedimentation, neutralization, chemical coagulation, and filtration. Other treatments include the removal of colors and odors and of settled, suspended, and dissolved solids, poisons, and other harmful substances such as cyanides, tars, acids, oil, sugars, soaps, detergents, alkalis.

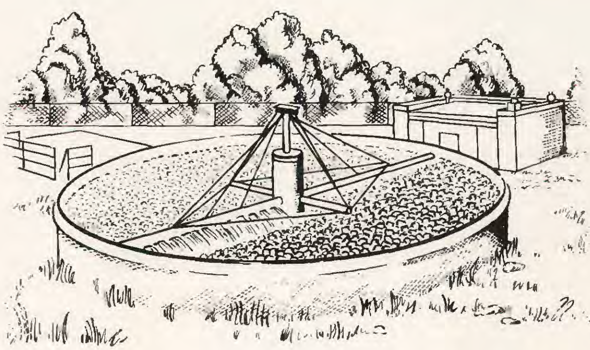
Agricultural Pollution Control

The silt and landwash derived from bare ground or freshly plowed fields is a kind of agricultural pollution to our streams. Corrective measures include better land management, reduction of soil erosion, and riverbed and bank stabilization. Similarly, shore erosion, concurrent turbidity, and deposition along Delaware Bay and the Atlantic Ocean represent a kind of land pollution, which can be controlled by bank and beach stabilization.

Nitrate may reach abnormally high concentrations in percolating ground water in areas under cultivation where nitrate fertilizers have been added to the soil. A nitrate concentration in excess of 50 ppm in water consumed by infants has been directly associated with methoglobinemia, a condition in which the skin becomes blue.

Insecticides have been associated with the killing of fish in ponds in Delaware. Spraying of fields permits wide distribution of materials which are potential contaminants.

While nature's water supply remains fixed, man's pollution load keeps increasing with population and with agricultural and industrial growth. The use of water must therefore be supervised vigilantly, for water is truly everybody's business.



ESTUARINE AND MARINE CONDITIONS

THE State of Delaware, bounded on the northeast and east by waters ranging from fresh in the upstream part of the Delaware River to salty ocean water off the Atlantic Coast, has an aquatic environment suitable for both fresh water and marine activities, especially commercial navigation and fishing. However, the shore, the sea, and the bay provide residents, vacationers, tourists, and sportsmen with many recreational activities, such as bathing, boating, and fishing.

In Sussex County, the State of Delaware has approximately 25 miles of beach front on the Atlantic Ocean which extends from Cape Henlopen to Fenwick Island. Approximately 8 miles of this beach front is public beach. Rehoboth and Bethany beaches on the Atlantic Ocean are the two main shore resorts in this area. The Indian River Inlet public camp ground is another recreational attraction.

The Atlantic Ocean

The Atlantic Ocean may be divided into open ocean, Gulf Stream, Continental Slope, and coastal waters. The Gulf Stream is a highly saline current of blue-appearing water whose upper stratum is relatively warm. On its western or inner side, the Gulf Stream is separated from the coastal waters by a zone in which the temperature falls abruptly and to which the term "cold wall" has been applied. East of the Continental Shelf the Gulf Stream flows generally northward. Inshore from here, the Continental Slope and coastal waters generally flow southward along the Atlantic Coast.

Offshore from Delaware, waters range from 90 percent open ocean near the coastline to 100 percent near the edge of the Continental Shelf. Maximum salinity in the coastal areas occurs in the fall and winter. Minimum temperatures of the coastal waters occur in winter and increase steadily to a maximum in the late summer.

Delaware River and Bay

The waters of the Delaware River and Bay range from fresh water at the Delaware-Pennsylvania State line at Marcus Hook to 90 percent or more sea water at Cape Henlopen and Cape May. Seasonally, the concentration of sea water in the river above Delaware Bay ranges generally from 0 to 40 percent, whereas in the bay it ranges from 2 to 90 percent. The tributaries of the river and bay area below the head of tide and the adjacent marshes are also subject to these seasonal variations in salinity.

The waters of Delaware Bay are usually of high salinity throughout the year, ranging from nearly pure sea water at Cape Henlopen to diluted sea water at Liston Point at the head of the bay. Although fresh water may extend into Delaware Bay from the Delaware River and from rivers tributary to the bay at times of very high fresh-water flows after heavy rains, the duration of the fresh-water conditions in the bay is short, usually a day or two, because of the mixing effect due to tidal action. The waters in Delaware Bay are generally less subject to sudden changes in salinity than are those in the upstream reaches of the Delaware River and tributary streams.

For convenience of discussion, the Delaware River and Bay area may be divided into a fresh-water zone containing less than 0.3 percent sea water, an intermediate zone containing 0.3 to 67 percent sea water, and a saline zone containing 67 to 90 percent or more sea water. During the winter and spring, the fresh-water zone extends to a point south of the Delaware Memorial Bridge below Wilmington and New Castle. When the Delaware River and its tributaries are at the flood stage, the fresh-water zone extends below Reedy Island Jetty. However, during periods of low river flow, salty water from Delaware Bay advances upstream. Generally, the most prolonged upstream advance of the intermediate zone occurs in the summer and fall, during which time the front of the intermediate zone is generally in the reach of the river above Marcus Hook.

Uses of Saline Water

Industrial Cooling

The Delaware River above Delaware Bay is economically important chiefly because it is used for navigation and as a source for obtaining large quantities of water for industrial cooling, chiefly for electrical generation, petroleum refining, and manufacturing. Approximately 820 mgd of Delaware River water was used by industries in Delaware in 1960, 19 times as much as the rated capacity (44 mgd) of the Wilmington Water Works. These industries use water ranging from fresh water to water containing 40 percent sea water.

Waterborne Commerce

Wilmington Harbor on the Christina River estuary, whose channel is 35 feet deep and 400 feet wide, is the main freshwater port in Delaware. Commodities transported in waterborne commerce are iron ore, paints, machinery, lumber, chemicals, and petroleum products.

The Chesapeake and Delaware Canal, in central New Castle County, is an important link of the inland waterway. (See fig. 3.) This canal, which connects the Delaware River at Reedy Point with Chesapeake Bay, affords favorable

FIGURE 3.—Waterway of commerce: the Chesapeake and Delaware Canal. Owing to alternate tides from Chesapeake Bay and Delaware River, this sea-level canal carries salty water to and fro. (Courtesy of the Delaware State Highway Dept.)

passage both for numerous local small craft and for pleasure craft on their seasonal passage north and south. About 19,000 boats of all types use the canal each year. The canal is also an important artery for commercial navigation. Waterborne commodities are agricultural products, coal, iron ore, phosphate rock, magnesite, lumber, petroleum products, iron and steel, machinery, fertilizers, chemicals, and wood pulp. About 450 ships pass through each month, carrying 10 million tons of cargo annually.

The U.S. Army Corps of Engineers has a current project (1964) for the enlargement of the canal: widening it from its present width of 250 feet to 450 feet, deepening it from the present channel depth of 27 feet to 35 feet, straightening the bends, and constructing mooring areas. Four highway crossings are being constructed with fixed-span bridges, and the new railway bridge will have a lift span.

Marshland Breeding, Hunting, and Trapping

In New Castle County there are approximately 35 square miles of marshlands most of which are in tidal areas. To-

The marshes of Delaware are the home of wildlife.

gether with the Delaware River and Bay, these marshes and their fresh-water tributaries are a natural habitat for waterfowl, muskrats, turtles, and fish. The marshes and adjacent areas are an important area for breeding, migrating, and winter refuge for waterfowl and a breeding and trapping ground for muskrats. In Kent County the Bombay Hook Migratory Waterfowl Refuge provides protection for wildlife.

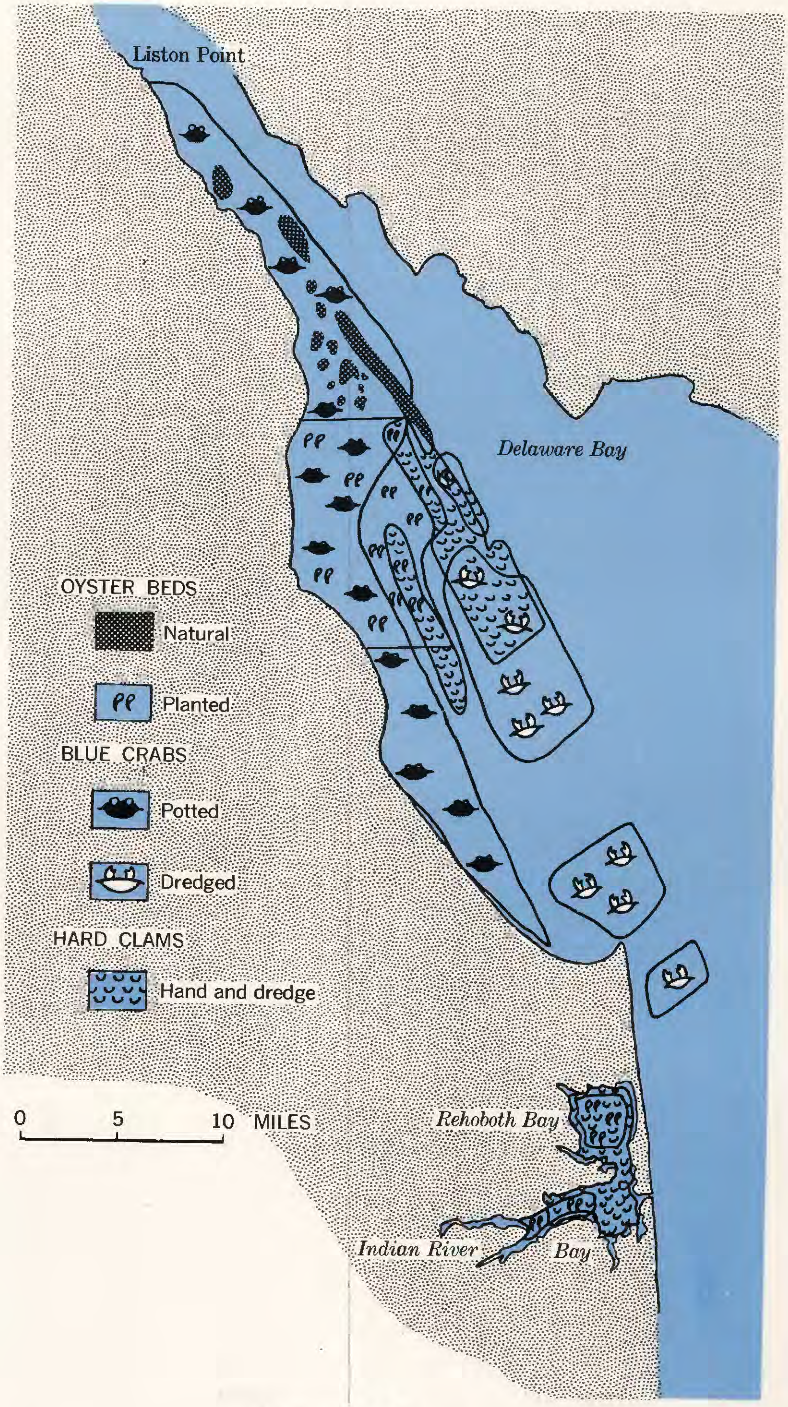
Marine Organisms

The large tidal area of the State of Delaware, especially in Kent and Sussex Counties, is one of the most favorable areas along the northern part of the Atlantic coast for the propagation and growth of marine organisms. This area includes 25 miles of coastline along the Atlantic Ocean, 90 miles of coastline along the Delaware estuary, and the marshland-tidal stream area, which makes up approximately 8 percent of the area of the State.

Numerous species of floating life (plankton), swimming life (nekton), and bottom life (benthon) are found throughout the estuary and in the offshore coastal waters. Salinity and temperature have a pronounced seasonal effect on the type and abundance of the species.

In winter and spring, the Delaware River and its tributaries have a high flow of fresh water from the uplands which dilutes the saline waters of the Delaware Bay and the coastal area. Many types of marine organisms are killed outright by river waters that are too fresh and too cold, while other types become dormant.

As the spring runoff decreases, there is a corresponding rise in salinity and temperature of the waters in the tidal area. Many types of organisms begin to grow and multiply, and tidal actions distribute them throughout the bay and coastal areas. Salt-water fish in their northward migration are attracted to feed on these organisms. The river, bay, and coastal areas are a favorite spawning ground. The shallow waters contain many species of small fish and the fry of the larger fish. These small fish, which feed on diatoms and other algae, minute crustacea, and organic matter held in



Major shellfishing areas.

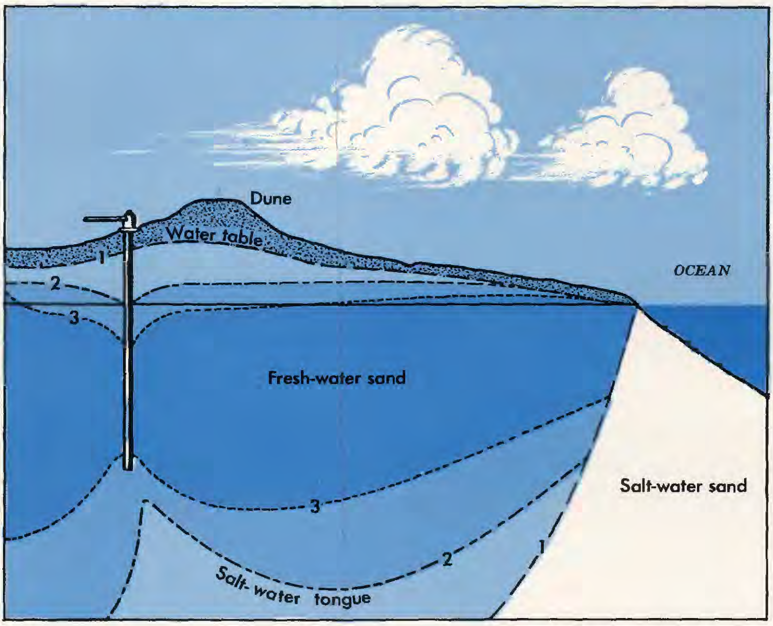
fine suspension or solution, in turn become prey for larger fish, crabs, and other marine predators. The fishing season is at its peak from June to September.

In addition to fish, shellfish such as oysters, clams, and scallops are influenced by salinity and temperature. Decrease in salinity resulting from floods of fresh water interferes with feeding, fattening, and reproduction of oysters and sometimes results in heavy mortalities. Oysters tolerate wide ranges in temperature, from freezing to 90°F, but spawn best at temperatures of more than 70°F; however, a drop in salinity to as low as 14 percent of sea water causes death after several days. Moreover, oysters require water containing an abundance of microscopic vegetation and a minimum of suspended inorganic particles or silt. The adjacent figure shows the major shellfishing areas.

Salt-Water Intrusion into Ground Water

Salt water from the sea has intruded the water-bearing sands in a narrow margin along the coast, both along Delaware Bay and the Atlantic Ocean. Inland intrusion may be only a few hundred feet, or it may be as much as half a mile. This wedge of salt water is a natural phenomenon due to the higher specific gravity of sea water, 1.025 compared with 1.000 for fresh water. The lighter fresh water floats on the salt water.

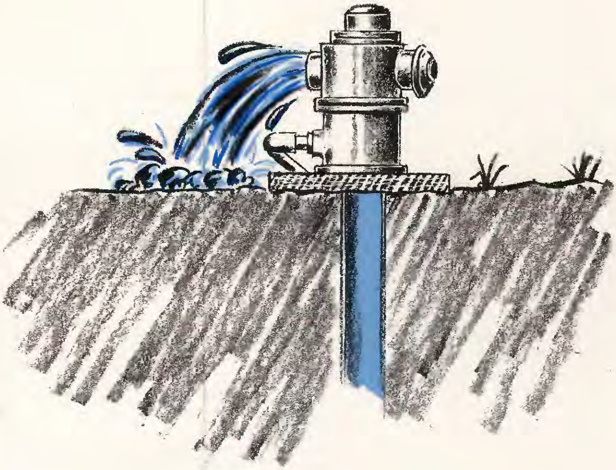
The interface between the fresh water and salt water is a zone of diffusion, or mixing, ranging from only a few feet to several hundred feet in width. Under static conditions, the interface between fresh water and sea water, which is about 2.5 percent heavier than fresh water, in permeable sand is at a depth of 40 feet below sea level for each foot the water table stands above sea level; that is, if the water table were 5 feet above sea level, the salt-water interface would be expected to be 200 feet below sea level. The actual depth of the interface depends upon the difference in specific gravity between the fresh and salt water, the rate of movement



Salt-water intrusion. Numbers 1, 2, and 3 show successive positions of the water table and of the corresponding interface between fresh water and salt water in response to pumping.

of fresh water toward the sea, the height of the fresh water above sea level, and the presence or absence of confining beds of silt or clay.

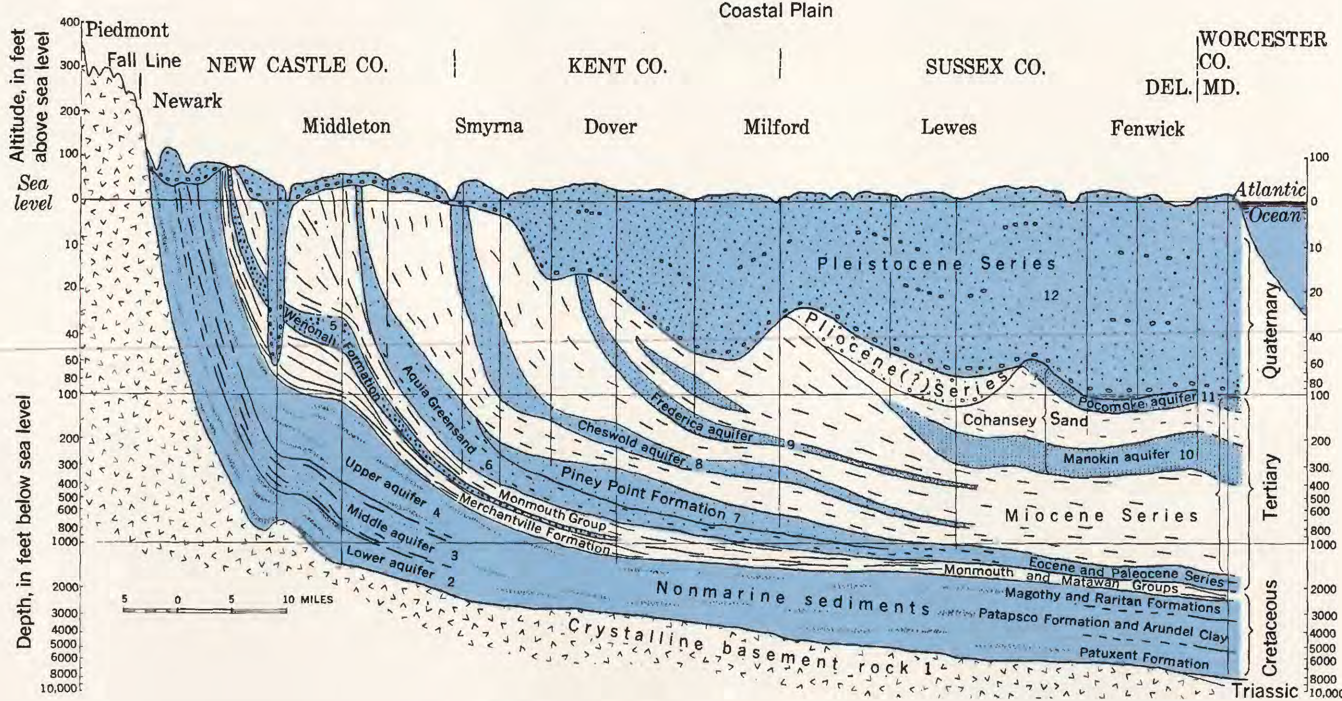
Salt-water contamination exists at Slaughter Beach, Lewes, Rehoboth Beach, and beneath parts of Fenwick Island in Delaware. The contamination at Lewes and Rehoboth was induced by large-scale pumping of the city well fields during World War II, as shown schematically in the above figure. Both these cities relocated their well fields at places a safe distance inland. Evidence at Lewes' old well field, no longer pumped, indicates that the salt-water interface has receded.



TWELVE GROUND WATER RESERVOIRS

GROUND-WATER reservoirs are different in many respects from surface-water reservoirs. First, the boundaries of the ground-water reservoirs are much less distinct and frequently are known only in part. The boundary between permeable and impermeable rocks may be sharp where, for example, crystalline rock abuts on a channel sand or along a fault, one wall of which is clay and the other, sand. At many places, however, the contact is gradational, the sand grading into silt and thence into clay. Also, the basement rock may be impermeable, or it may be leaky and take or give some water. Likewise, the confining strata may be tight or leaky, retaining water or allowing water to enter or escape. The water is not at a fixed level throughout the reservoir, but slopes from the high points of intake, or recharge, to low points of discharge. Movement of ground water is slow, usually only a few feet a day, and it is possible for the reservoir to be overflowing in one area, and yet to have a well-developed cone of depression in the water surface several miles away. Likewise the water may be of a quality suitable for all purposes in one sector, but owing to dissolved solids, the water is suitable only for certain purposes elsewhere. The storage capacity of the reservoir may range from a fraction of 1 percent to 30 percent of the volume of the producing sand. The coefficient of transmissibility, ideally a constant, may change from place to place within wide limits. Any similarity between a ground-water reservoir and a surface-water reservoir is strictly coincidental: they both contain water.

Broadly speaking, there are 12 principal ground-water reservoirs in Delaware, as shown in the cross section of the State. These reservoirs are technically termed "aquifers," a term used for an integral water-bearing unit. The silts and clays that separate the aquifers are called "aquicludes," from the Latin words meaning "to enclose water." The reservoir number given after each of the following headings refers to the number in the geologic cross section.



Twelve ground-water reservoirs in cross section.

Crystalline Rock: Reservoir 1

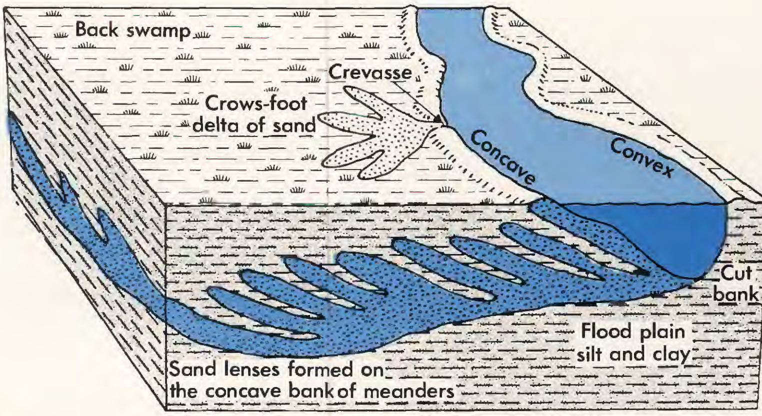
The Piedmont of Delaware is underlain by hard crystalline rocks of gneiss, schist, gabbro, granodiorite, and granite, mantled in most places by weathered residual clayey soils. Boulders and bosses of rock protrude on the slopes and line the running streams. Considerable ground water is stored in the gneiss and schist areas, but it is contained in fractures and fissures and moves slowly. It sustains many springs and seeps that emerge near the bottom of relatively deep valleys.

Wells are, in general, of small yield, being adequate only for domestic purposes. Dug wells, generally less than 30 feet deep, derive water from the base of the weathered zone. Drilled wells range from 50 to 300 feet in depth and derive water from the rock itself. Two small areas of Cockeysville Marble provide slightly greater yields of water than comparable areas of other formations in the Piedmont, but the water is hard. In some places north of Wilmington, the gabbro is so tight that only meager supplies are obtained from it. In these places additional water is obtained from a clayey gravel terrace, 300 to 400 feet in altitude, which overlies the gabbro.

The crystalline rocks form the "basement" beneath the Coastal Plain, sloping southeastward at a rate of 90 feet to the mile; therefore, beneath Fenwick Island they lie more than a mile and a half below sea level. The basement rocks yield little or no water to wells.

Nonmarine Cretaceous Reservoirs

A great sheaf of fluviatile sands and clays forms several aquifers, known, for want of better terminology, as the lower aquifer, the middle aquifer, and the upper aquifer. The lower and middle aquifers may be related to the Patuxent and Patapsco Formations, but conclusive correlation is lacking. Likewise, the upper aquifer is apparently related to



Schematic diagram of the development of aquifers in the nonmarine sediments.

the Magothy and Raritan Formations. The above figure shows a schematic diagram of the development of aquifers in nonmarine sediments.

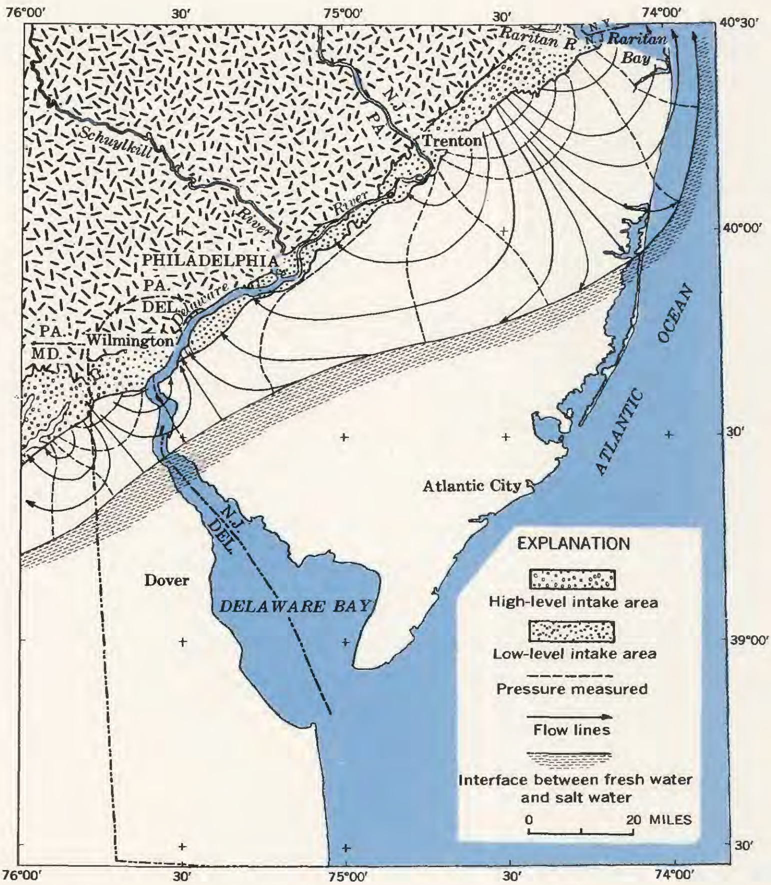
The theoretical flow pattern in these formations is illustrated in the adjacent figure to show how water moves from intake points, at high levels, to discharge points, at low levels. A theoretical interface between fresh water and salt water is depicted. The map underlines the fact that the flow of ground water is not controlled by political boundaries.

Lower Aquifer: Reservoir 2

The lower aquifer is the lower sandy zone of the nonmarine Cretaceous sediments. The sands are buff colored and silty. The enclosing clays are variegated red, white, and gray. Yields for 52 wells ranged from 3 to 800 gpm (gallons per minute), and averaged 104 gpm. The average specific capacity of 22 wells, in gallons per minute for each foot of drawdown, was low (2.0).

Middle Aquifer: Reservoir 3

The middle aquifer of the nonmarine Cretaceous sediments consists of fine to medium sand and silty sand inter-



Flow pattern of fresh water in nonmarine sediments of Cretaceous age.

bedded with varicolored silts and clays. Yields of 29 wells ranged from 12 to 500 gpm and averaged 89 gpm. Specific capacity averaged only 1.6 gpm per foot of drawdown, based on 21 wells.

The middle aquifer is probably hydraulically connected to the lower aquifer because the channel sands interfinger in the subsurface. An extensive cone of depression in the pressure-measured water surface has developed in the lower and middle aquifers in the Delaware City area since 1955. The decline of water level in three observation wells in these aquifers ranged from 41 to 50 feet between 1954 and 1957 in wells 5 to 7 miles from the center of pumping. During this period, pumping in the Delaware City area increased from half a million gallons a day to nearly 5 mgd, most of which was derived from these aquifers.

Upper Aquifer: Reservoir 4

The upper aquifer consists of fine to medium usually well-sorted white and gray sands and lenses of red, gray, white, and yellow clays. Yields of 24 wells ranged from 7 to 538 gpm and averaged 100 gpm. Specific capacities ranged from 0.12 to 6.8 gpm per foot of drawdown and averaged 2.3 gpm per foot. These specific capacities are larger than those of the lower or middle aquifers. Water levels in 49 wells in the upper aquifer ranged from 2 to 55 feet below land surface and averaged 28 feet. The decline in head in the Delaware City area was only 12 feet between 1954 and 1957, as observed in a well 4 miles from the center of pumping. The upper aquifer is not pumped as heavily as the middle and lower aquifers, and the hydraulic connection may be devious.

The flow pattern indicates that the danger of intrusion of salty water from the Delaware River is everpresent; if the fresh-water head should decline to below sea level, the discharge area where the aquifer underlies the Delaware River would then become an intake area for salty water.

Wenonah and Mount Laurel Formations: Reservoir 5

Sands in the marine deposits of Cretaceous age yield moderate to small quantities of water to wells in southern New Castle County, south of the Chesapeake and Delaware Canal. These sands are correlated with the Wenonah and Mount Laurel Formations of New Jersey. In the outcrop along the canal the sands are gray and brown, but in samples from wells the sands are green and white. Most of the wells drilled in these sands are for domestic use. The maximum yield reported by the drillers is 165 gpm for Middletown; the average yield is about 30 gpm.

Until 1957 only a few domestic wells were developed in the Piney Point Formation in Delaware, all of them in northeastern Kent County. In April of that year, a deep test well at the Dover Air Force Base showed that the Piney Point Formation was about 250 feet thick and that the top was 334 feet below the land surface. The formation is a well-sorted medium-grained quartz sand that contains disseminated grains of greensand (glauconite). The water is under artesian pressure, rising at the well from a depth of 316 feet to a static level 18 feet below the land surface and 6 feet above sea level. The 6-inch well was test pumped for 12 hours at 211 gpm with a drawdown of 25.5 feet, indicating a specific capacity of 8.3 gpm per foot of drawdown.

About 315 feet of drawdown is available before the top of the producing sand is reached; high-capacity wells could therefore be developed in this formation, if the aquifer characteristics remain favorable for sufficient distances from the airbase. One limiting geologic factor is the lack of a recognizable intake area for the sand. Perhaps sufficient recharge water could move across formation boundaries, from the lower Eocene sands or from basal Miocene beds, but this possibility has not yet been demonstrated.

The water is moderately high in dissolved solids (331 ppm), slightly hard (82 ppm as $CaCO_3$), low in iron (0.24 ppm), rather high in bicarbonate (342 ppm), is mildly alkaline (pH=8.1). It is suitable for most purposes.

It is expected that the Piney Point Formation will eventually be extensively used in central Delaware, especially in southern Kent County.

Cheswold Aquifer: Reservoir 8

The chief water-bearing sand supplying the capital city of Dover and environs is called the Cheswold aquifer, after the town of Cheswold, about 5 miles north of Dover, even though Cheswold has obtained only modest supplies of water from the aquifer. Cheswold, however, is centrally located

Aquia Greensand and Vincentown Formation: Reservoir 6

The Tertiary System in Delaware is represented by four series: the Paleocene Series (not exposed except as found in wells), which consists chiefly of clays and very fine sands; the Eocene Series, which contains at least two aquifers; the Miocene Series, which contains at least four aquifers; and the Pliocene Series, which functions as a hydraulic unit with the overlying Pleistocene Series of the Quaternary System.

The basal aquifer of the Tertiary System consists of two parts: a lower limey sand, equivalent to the Vincentown Formation (Paleocene) of New Jersey, and an upper green quartz sand, equivalent to the Aquia Greensand (early Eocene) of Maryland and Delaware. The upper sand crops out around Noxentown pond in southern New Castle County and underlies the Pleistocene Series in a narrow intake belt. It is gray and green and is sometimes called salt-and-pepper sand. The green grains are a soft micaceous mineral, called glauconite, that forms chiefly under marine conditions of sedimentation.

These sands compose an important aquifer in southern New Castle County and northern Kent County. Most of the wells tested at 30 gpm, and, so, are adequate for domestic use. One well at the town of Clayton is reported to yield 370 gpm. The water is hard, 154 ppm as calcium carbonate, but otherwise usable for many purposes.

Piney Point Formation: Reservoir 7

A sand of late Eocene age, containing microfossils similar to those of a type locality at Jackson, Miss., has been found only in the subsurface in Delaware; it promises to be an aquifer of importance. It is called the Piney Point Formation after the type locality in southern Maryland, an area where wells of large capacity have been developed.

over the part of the aquifer now in use. The intake area for the Cheswold aquifer is a belt that lies north of the Smyrna River and that trends southwestward beneath a mantle of coversand of Pleistocene age. From Smyrna, where the sand is found at depths close to sea level, it dips southeastward to Dover, where it is about 125 feet below sea level, and beyond to Dover Air Force Base, where it is 175 feet below sea level.

Test yields of 12 wells in the Cheswold aquifer, each 6 to 14 inches in diameter, ranged from 70 to 781 gpm and averaged 374 gpm. The average specific capacity was 10.5 gpm per foot of drawdown. The water is suitable for most purposes but is moderately hard (about 110 ppm as $CaCO_3$) and contains moderate concentrations of dissolved solids (about 205 ppm).

Stratigraphically, the Cheswold aquifer is in the lower part of the Miocene Series, as it is underlain by a diatomaceous clay and overlain by gray and blue silts and clays. The Cheswold aquifer consists of gray medium to coarse sand containing shell material; the sand ranges from 20 to 60 feet in thickness.

The Cheswold aquifer is used principally in the northern half of Kent County. At Dover, the cone of depression amounts to a decline of about 80 feet over the last 40 years, a change from flowing wells to fairly deep operating levels. About 80 feet or more drawdown is available in most places before the top of the producing sand is reached; there is therefore little cause for alarm. However, the decline in water levels in the Cheswold aquifer at Dover Air Force Base did prompt the officials to prospect for deeper supplies; this exploration resulted in the discovery of the Piney Point Formation. Although the Piney Point Formation lies 90 feet deeper and wells tapping it would consequently be more expensive and although the water is slightly higher in dissolved-solids content, the formation has a higher head than the Cheswold aquifer and may prove to be a worthy supplemental supply. However, the Cheswold aquifer is anticipated to continue to be the principal source in this area for many years to come.

Frederica Aquifer: Reservoir 9

In the southern half of Kent County there is another water-bearing bed in the Miocene Series that is stratigraphically higher and, so, younger than the Cheswold aquifer. This aquifer has in the past been the principal source of water for Milford. Because Frederica is centrally located in the area of principal use and because this town derives its water from the aquifer at a depth of about 145 feet, the water-bearing sand was named the Frederica aquifer.

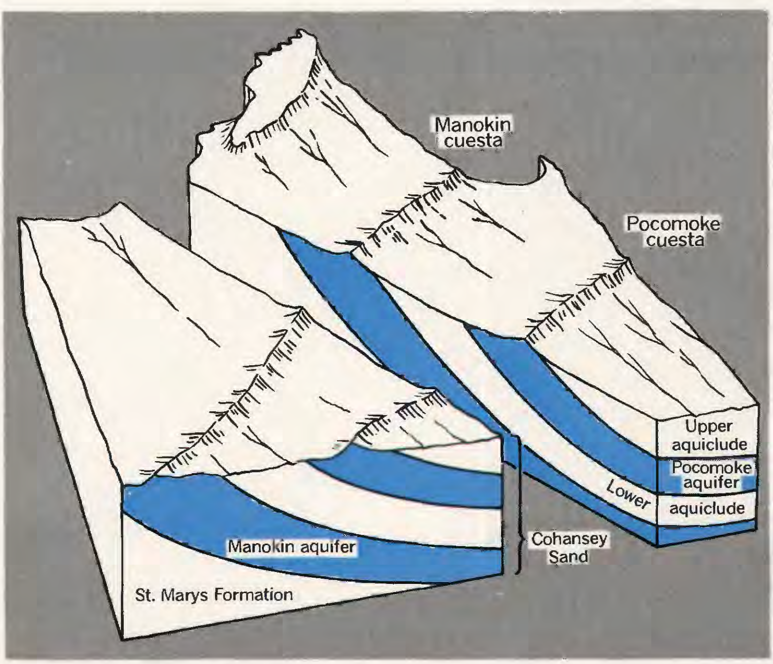
The intake area, where the sand is at the surface or close to the surface but beneath coversand of Pleistocene age, is a narrow belt that trends northeastward and passes beneath Dover. From the intake area at altitudes close to sea level, the sand dips progressively deeper, beneath a confining bed of silt and clay, to 70 feet below sea level at Felton, 125 feet below sea level at Frederica, 140 feet below sea level at Harrington, and 200 feet below sea level at Milford. The aquifer is gray medium to coarse sand, having an average thickness of 20 feet in southern Kent County.

The maximum reported yield is 550 gpm from an industrial well in Wyoming. The average yield of 12 industrial and municipal wells is about 260 gpm, and the specific capacity is about 6 gpm per foot of drawdown. Water obtained from the Frederica aquifer is commonly reported to be hard and at places high in iron.

Manokin Aquifer: Reservoir 10

The Cohansey Sand of Miocene(?) age is an extensive and fairly thick sand covering the southern Coastal Plain of New Jersey. The Yorktown Formation of Miocene age is an extensive shell sand of southern Virginia and the Virginia Eastern Shore. Both of these are the uppermost units of the Miocene Series in their respective areas. On the Eastern Shore of Maryland these sands were recognized and correlated from samples in wells. The unit was divided into a basal sand called the Manokin aquifer, a sandy silt called the lower aquiclude, an intermediate sand called the Pocomoke aquifer, and an overlying sandy silt called the upper aquiclude.

This four-fold division has been applied also in Sussex County, Delaware, but only as a provisional working hypothesis. The entire County is mantled with Pleistocene materials, and the number of wells drilled to the Cohansey Sand is too few, considering the area, to arrive at any conclusions. Moreover, many of the wells penetrate only a few feet or a few tens of feet into the Miocene Series and do not present a full section. Only a few have been carefully logged and sampled. The Cohansey Sand underlies the Pleistocene and Pliocene deposits beneath the southeastern two-thirds of Sussex County. It ranges in thickness from 1 foot near Seaford to 280 feet beneath Fenwick Island.



Upper part of the Miocene Series in Sussex County, shown with the overlying Pliocene and Pleistocene deposits removed.

The Manokin aquifer, a gray sand and silt that is the basal unit of the Cohansey Sand, is as much as 100 feet thick (Bethany Beach area). The Manokin aquifer is underlain by clays of earlier Miocene sediments and overlain by a sandy silt in the area southeast of the intake area. In many places, such as at Laurel and at Georgetown, the Manokin aquifer yields water in conjunction with overlying sands of the Pleistocene and Pliocene(?) Series. Properly constructed wells have yielded 500 to 1,100 gpm, and their specific capacities have been as much as 44 gpm per foot of drawdown. The water is suitable for almost all purposes, as it is relatively low in dissolved solids and iron and is soft.

Pocomoke Aquifer: Reservoir 11

The Pocomoke aquifer is an intermediate unit in the Cohansey Sand yielding water to wells in the southeast corner of Sussex County. The intake area of the Pocomoke aquifer is completely buried beneath permeable deposits of the Pleistocene Series. It forms a belt about 6 miles wide passing beneath Selbyville, Frankford, Dagsboro, and Indian River Inlet. Fifteen moderate- to large-capacity wells, drilled into the aquifer at depths ranging from 60 to 185 feet, have yields ranging from 70 to 500 gpm and specific capacities ranging from 2 to 24 gpm per foot of drawdown.

The Pocomoke aquifer shows considerable variation in the quality of its water, as might be expected owing to its nearness to estuary and ocean waters and to the way it is cut up by channels now choked with deposits of Pleistocene fill. The waters range from soft to hard and are generally fresh except beneath Bethany Beach, where there is some indication that the aquifer has been contaminated by sea-water intrusion. With one exception, the waters contain high concentrations of iron.

Pleistocene and Pliocene(?) Series: Reservoir 12

The Pleistocene Series, in places in conjunction with the Pliocene(?) Series, is the most important aquifer (or aquifer group) in Delaware. The Pleistocene Series is the surficial sand and gravel deposits that mantle most of the Coastal Plain. These deposits range in depth from a few feet on flat surfaces to as much as 150 feet in deep filled channels. In character, the Pleistocene deposits are tan to brown coarse to fine sands, containing layers of gravel and silt and minor lenses of silt and clay. The deposits referred to as Pliocene(?) are of questionable age and may be Miocene or Pleistocene. They are red to brown gravelly sands which occupy some of the deeper filled valleys beneath the Pleistocene Series.

The intake area of the Pleistocene Series covers almost all the Coastal Plain. Recharge is from infiltration of rainfall and from seepage of streams at flood stage. The soils are sandy loams, which are remarkably absorbent; so, infiltration rates are high. Much of the water that recharges other formations must first pass through the Pleistocene sediments. There are only a few localities in which less permeable beds of silt and clay, within the Pleistocene Series, create local artesian conditions. These are mostly along the ocean and bay shore.

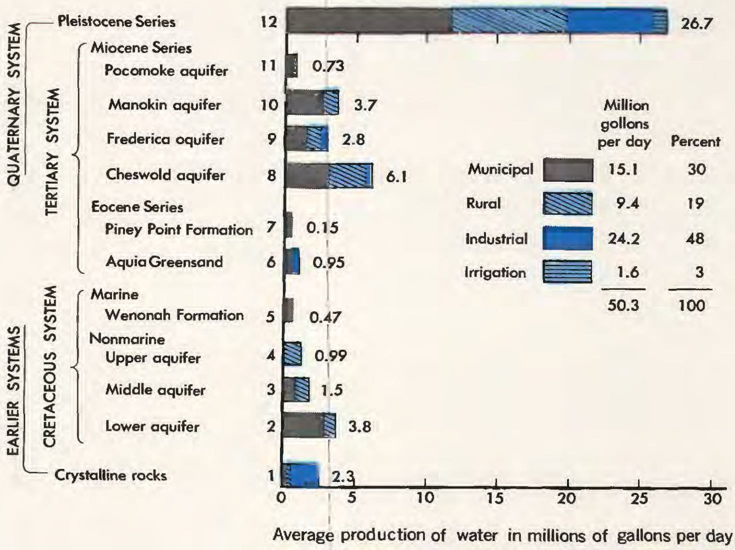
In some of the shore areas the sands of the Pleistocene Series have been contaminated with salt water. Examples of this contamination are beneath the beaches of Lewes and Rehoboth. Fortunately, both these resorts have developed fresh-water supplies from new well fields a mile or more inland.

In northern Delaware, the thickness of the Pleistocene Series, based on 376 well records, averages 36 feet, ranging from 2 to 115 feet. The sands and gravels have coefficients of transmissibility ranging from 10,000 to 140,000 gpd per ft (gallons per day per foot) and coefficients of storage ranging from 0.01 to 0.20.

In central Delaware the Pleistocene Series is not as well known, but in general is no thicker than in northern Delaware. Channel sands in the vicinity of Smyrna form an excellent aquifer.

In southern Delaware, the Pleistocene Series is the principal aquifer in Sussex County and supplies water to Greenwood, Bridgeville, Seaford, Laurel, Delmar, Lewes, Rehoboth, Millsboro, Dagsboro, Frankford, and Selbyville. Sixty-seven tested wells, of both large and small construction, showed yields ranging from 12 to 1,000 gpm and specific capacities ranging from 1 to 31 gpm per foot of drawdown.

The quality of water from the Pleistocene Series is, in general, suitable for most purposes. Except for a few analyses from wells whose water is contaminated with salt water along the coast, the water is generally low in dissolved solids; that is, less than 100 ppm. The water is usually soft, or only moderately hard, containing no troublesome constituents except iron. The content of iron is sporadic; in some wells it is very low, in others it is as much as 8.0 ppm. The pH is commonly low and may require some adjustment to avoid corrosion of pipes.



Bar graph of water produced.

Comparison of the Ground-Water Reservoirs

The rate of water produced from the 12 ground-water reservoirs in 1957 was 50.3 million gallons a day and is illustrated in the adjacent bar graph. In 1964 this figure is estimated to be at least 15 percent higher.

The Pleistocene Series (in conjunction with the Pliocene(?) Series in a few places) is by far the most important aquifer in Delaware, providing 53 percent of all ground water produced in 1957. The advantages of the Pleistocene Series are:

1. Wells are generally less than 100 feet deep and are relatively easy to drill.
2. Recharge is from infiltrating rainfall or from influent seepage. Other recharge sources (ponds and streams) are usually nearby.
3. The predominant sands are medium to coarse, containing layers of grit and gravel. Fine sand, silt, and clay commonly compose less than 40 percent of the formation.
4. The coefficients of transmissibility and storage of the formation are moderate to high. The coefficient of transmissibility ranges from 10,000 to 140,000 gpd per ft and the coefficient of storage from 0.01 to 0.30, depending upon the location.

The Pleistocene Series also has some disadvantages which, in places, become of overriding importance:

1. Along the shore the sands are frequently intruded by salt water.
2. Competing outlets of natural discharge—seeps, springs, and evapotranspiration "bays" and "basins"—are close by at many well sites. The well, however, has the advantage, as it is deeper.
3. In many places the Pleistocene Series is too thin for adequate wells. Except in most of Sussex County, where the Pleistocene Series is widespread, it is confined to filled channels.
4. The occurrence of iron is troublesome in some waters derived from the Pleistocene Series.

5. Available drawdown is not large, commonly only a few tens of feet. As the drawdown increases, the saturated thickness decreases, the coefficient of transmissibility decreases, and the quantity of water produced is throttled.

Nevertheless, in Delaware the Pleistocene Series is expected to remain the most important aquifer, in number of wells tapping it, in highest rates of yield, and in total quantity of water produced.

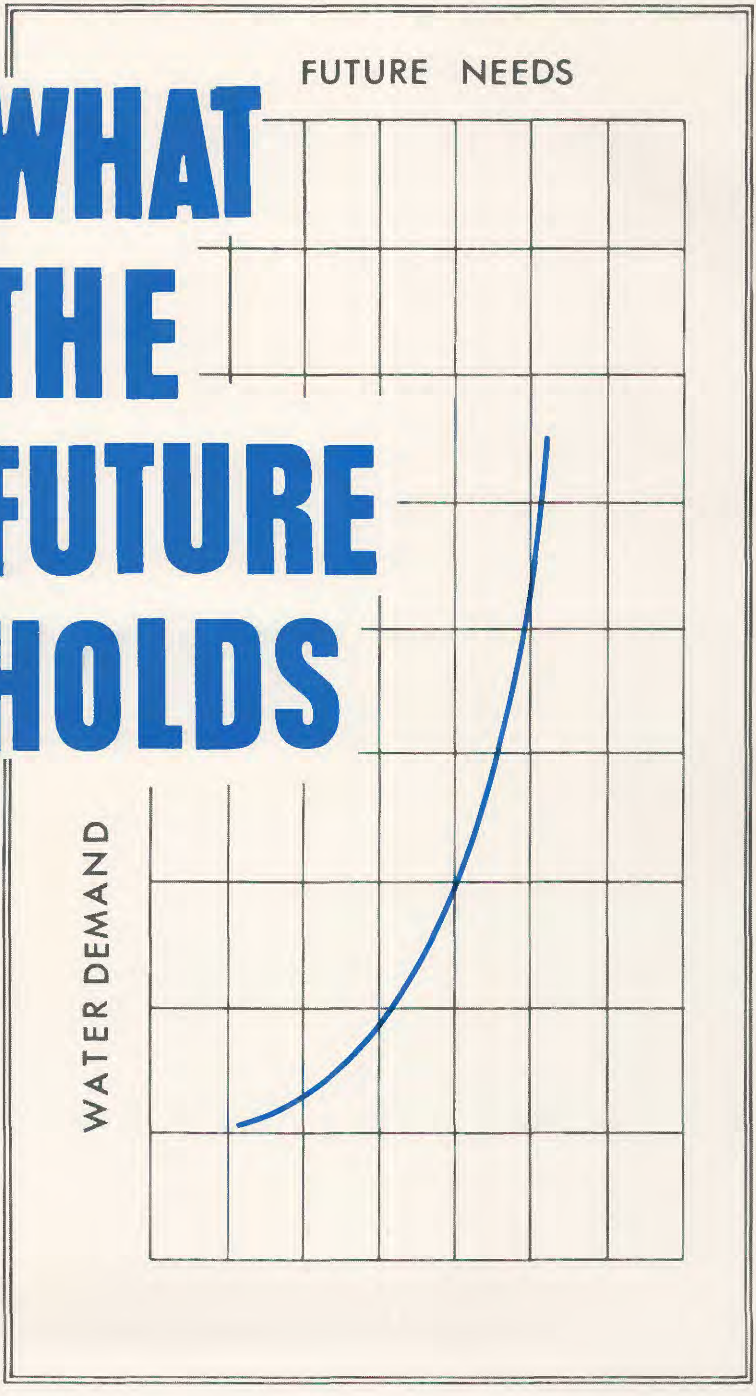
The Miocene Series is the second most productive aquifer group in Delaware, providing water to many wells in the central part of the State and to some wells in the southern part. The four aquifers of the Miocene Series provide 27 percent of the ground water produced in 1957: the Cheswold aquifer provides 12 percent; the Frederica aquifer provides 6 percent; the Manokin aquifer provides 7 percent; and the Pocomoke aquifer provides 2 percent of the ground water produced.

The nonmarine Cretaceous sediments, divided into a lower, middle, and upper aquifer, provided 13 percent of the ground water produced in Delaware in 1957. Of these, the lower aquifer provided almost 8 percent; the middle aquifer, 3 percent; and the upper aquifer, 2 percent.

The marine Cretaceous sediments (the Wenonah and Mount Laurel Formations) and the Eocene Series (Aquia Greensand and the Piney Point Formation) provided relatively small quantities of water, chiefly to domestic wells, and accounted for only 3 percent of the ground water produced in Delaware in 1957. The Piney Point Formation has greater potential for development.

The water produced from the crystalline rocks was 4.6 percent of the total ground water produced in Delaware in 1957. This rather surprising total was derived from many farm and domestic wells, each producing water at relatively low rates. The yield from the crystalline rocks will remain moderate to low.

WHAT THE FUTURE HOLDS



Population and Water Demand

The rising population of Delaware is a source for concern in the future. The population was about 60,000 inhabitants in 1790, mostly rural; the growth rate up until 1840 was gradual, about 3,000 a decade. Between 1840 and 1930 the development of cities, as part of the industrial revolution, caused a relatively large increase in the growth rate to about 18,000 persons a decade, of which only about 5,000 persons were rural. From 1930 to 1950, there was another upturn to a rate of about 65,000 persons a decade. During the last 10 years (1950 to 1960) the population has increased by 125,000 persons, as the result of a great influx of people to northern Delaware. The projected trend would indicate that in 50 years, by the year 2010, the population may be more than 1,400,000 persons. The Senate Select Committee on National Water Resources estimates the population of Delaware for the year 2000 at 1,300,000.

In addition to the rapid population growth now being experienced in Delaware, there is a concurrent rise in water needs for each person—the "per capita demand." In mid-century the water use per person exceeded 1,000 gallons a day for all domestic, industrial and agricultural needs. In the year 2000, the water use per person may well exceed 1,500 gallons a day. This estimate is conjectural, however, because it depends upon technological progress and processes not yet conceived. Such an estimate does not apply specifically to Delaware but to our Nation as a whole. By then, Delaware will be as industrially developed and agriculturally advanced as any other comparable area in the United States. Irrigation of farms in Delaware will be commonplace. More intensive agriculture will be necessary in this State, which has surrendered many acres of arable land to industry, commerce, and residential growth.

Moreover, the irrigation potential in Delaware is large. Nearly 500 square miles, one-fourth of the land area of the State, is potentially irrigable. Demands for water for irrigation must be met from the surface- and ground-water reservoirs. Large truck farms, similar to those in New Jersey, are feasible.

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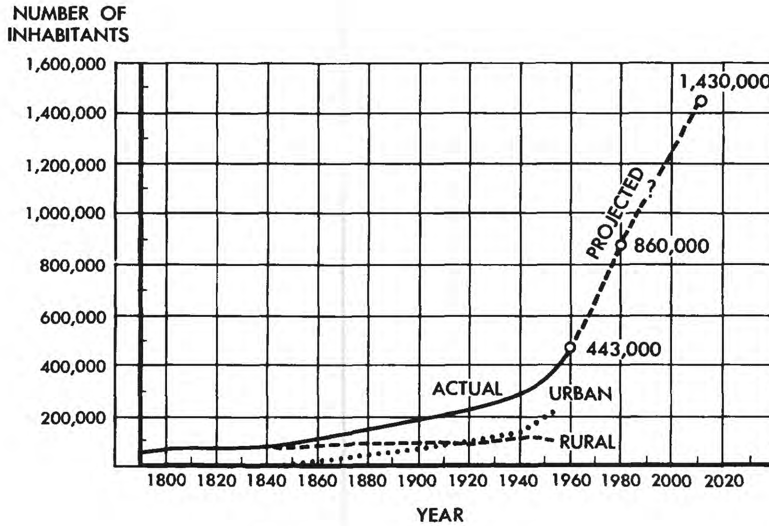
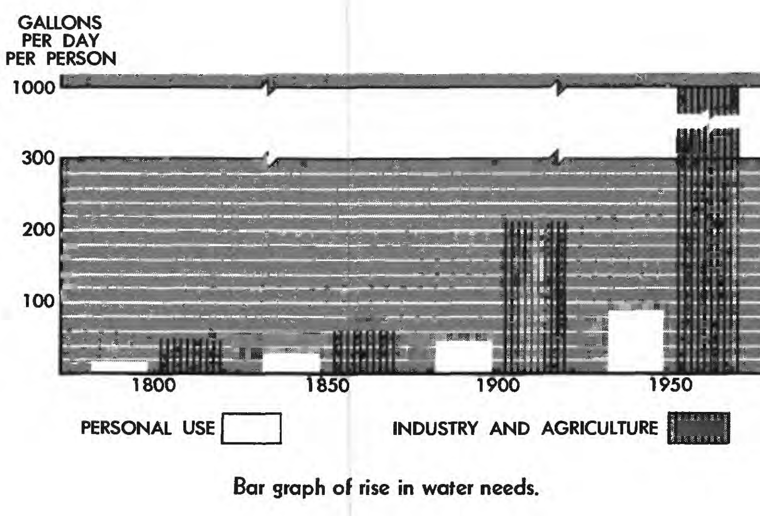


Graph of population growth.



Bar graph of rise in water needs.

Water Is Where You Find It

In northern Delaware, north of the Chesapeake and Delaware Canal, processed water is already in short supply. This shortage is not due to inadequate water resources but to population and industrial growth, which has been so rapid that waterworks can barely keep pace with demand. Also, the water authorities are not willing to pay the cost of additional water, and they are reluctant to finance expensive development by raising taxes or the rate of processed water to the consumer or by going into bonded indebtedness.

In the remainder of Delaware, south of the canal, water of quality suitable for most purposes is generally available at low to moderate cost. In a few localities, however, the shallow formations do not yield enough water or the water is of undesirable quality; at these places there has been reluctance to prospect for deeper supplies or to develop surface-water sources. Water in these places is available, but it is not cheap.

Data obtained by the Senate Select Committee show that, except for Maine, Delaware obtains municipal water more cheaply than any other State in the Nation. The water problem, then, for the State of Delaware is development of the least expensive supply of water of suitable quality. In the solution of this problem the following possible approaches should be considered:

- Small surface-water reservoirs.
- Barrier dam on the tidal Delaware River.
- Importing water from streams in Pennsylvania, Maryland, or New Jersey.
- Network of wells on the Coastal Plain.
- Artificial recharge to aquifers.
- Conservation of water by reuse.
- Desalting water of the tidal estuaries and other sources.

Small Surface-Water Reservoirs

One solution proposed to the water problem in northern Delaware is the construction of many small reservoirs, similar to the Hoopes Reservoir (fig. 4), on Brandywine Creek, Red Clay Creek, Pike Creek, Mill Creek, White Clay Creek, and the Christina River. Such reservoirs could be installed at perhaps 15 to 20 sites in Delaware. Additional sites where small impoundments could be made are in Pennsylvania and Maryland on the upper reaches of these streams, but some equitable interstate distribution of water would have to be arranged with the residents concerned.

Not all the sites would be self-sustaining; that is, the runoff in the drainage basin of each tributary would not be enough to refill many of the reservoirs used continuously for water supply. Such an example is the drainage basin supplying Hoopes Reservoir, which is refilled by pumping surplus water from Brandywine Creek during periods of adequate runoff. Similarly, many of these smaller reservoirs would have to be refilled, by gravity conduit or by pumping from the parent stream, during periods of high water.

At present, northern Delaware has the following estimated storage capacity:

	Million gallons
Hoopes Reservoir (on a tributary to Red Clay Creek)	2,200
Smalleys Pond (on Christina River)	40
Bellevue Reservoir (Stoney Creek basin north of Wilmington)	100

FIGURE 4.—Hoopes Reservoir, a reserve water supply for the city of Wilmington. A prototype for small reservoirs in northern Delaware. (Courtesy of the Brandywine Valley Association.)

The Brandywine Valley Association (Wilmington, Del.) has proposed construction on Brandywine Creek of four reservoirs whose individual capacities would exceed 1,400 million gallons. The construction of only two of the proposed reservoirs would more than double the present storage capacity for the entire region and greatly minimize the need for additional storage on other streams.

The potential development depends largely on the use of the storage reservoirs to increase the safe yield of the developed stream. Hoopes Reservoir is used only as a reserve for the city of Wilmington. If this reservoir were operated for daily supply, the water level would be lowered 50 to 60 feet during periods of withdrawal and would be restored by transfer from Brandywine Creek (or other source) during periods of surplus flow.

An estimated 60 mgd of fresh water was withdrawn from the Christina River system (including Brandywine, Red Clay, and White Clay Creeks) in 1957. If a storage capacity of 3 mgsm (million gallons per square mile) were established on this system, the allowable draft at a 10-year recurrence interval would be 136 mgd, more than double current use. If 30 mgsm were established, the allowable draft would reach 248 mgd, more than four times the current use. Cost of storage facilities to provide a 3-mgsm capacity would be moderate. Cost of storage to provide 30 mgsm would be relatively high and would require the acquisition of much valuable real estate.

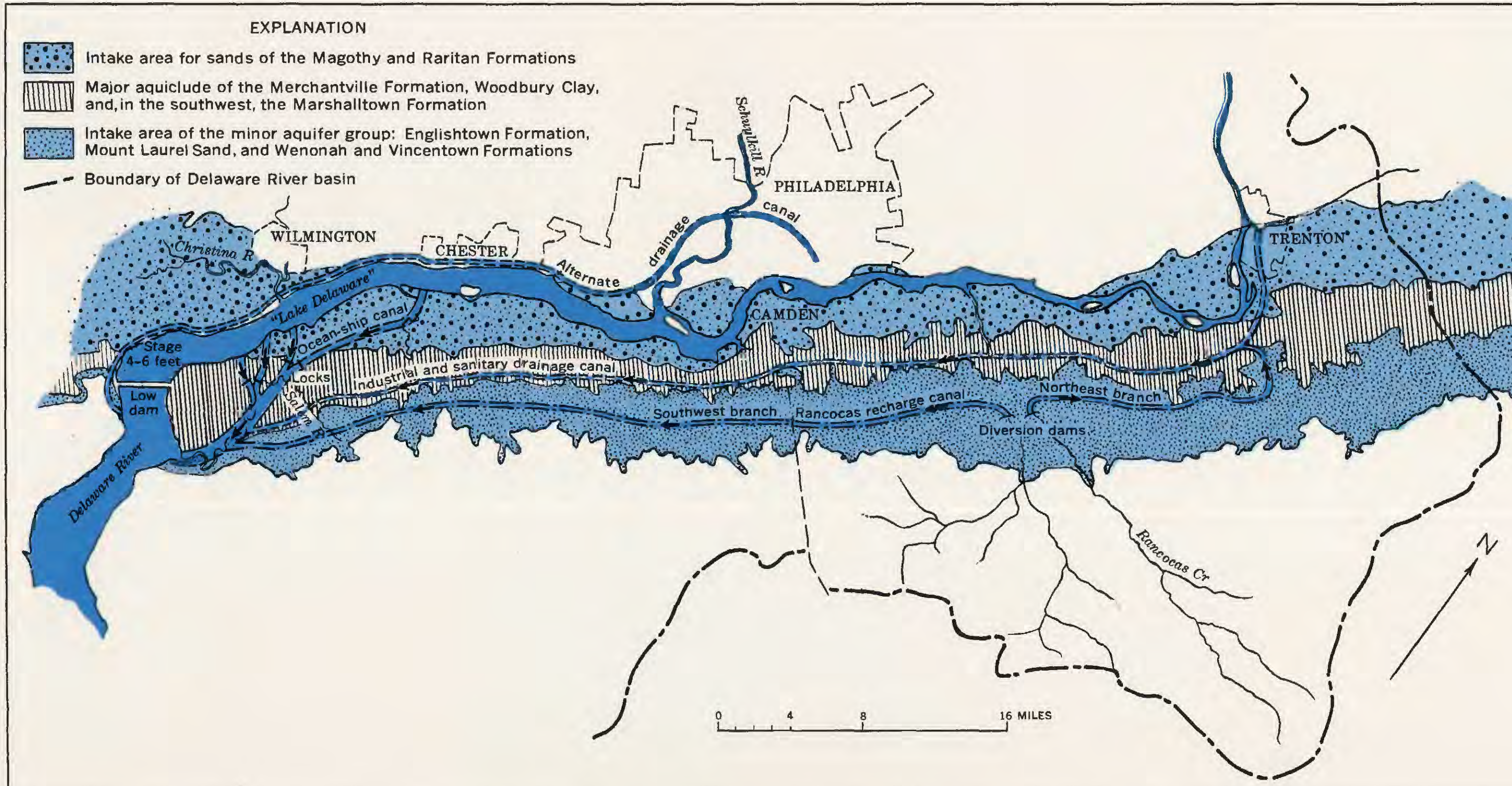
Some surface-water storage facilities could also be provided on the Coastal Plain, but because of the flatness of the land the reservoirs would have much surface area but only shallow depth. Evaporation opportunity would therefore be large. Some benefit would accrue by bank storage, recharging ground-water levels locally, but this benefit could be offset by drainage problems. Nevertheless, in a full-scale management program of water resources, small check dams on the streams of the Coastal Plain may eventually provide an important means of supply. The feasibility of such storage facilities is exemplified by many mill ponds constructed years ago, many of which are still maintained for recreational purposes.

For example, the average discharge determined at five gaging stations in or near Sussex County is 743,000 gpd per sq mi. If this figure is rounded to 0.7 mgd per sq mi and is taken as being representative of the county as a whole, whose land area is 946 square miles, the average discharge of surface-water runoff is about 670 million gallons a day. Much of this water is naturally useful, as it dilutes wastes and aids in the preservation of the natural habitat for water plants and animals. The consumptive use, mainly for irrigation, reached an estimated 205 mgd during the summer of 1957. During most of the year, however, the consumptive use of surface water is only a few million gallons a day. Therefore, an average of about 500 mgd of surface water discharges for which there is no consumptive use. Perhaps an additional 200 mgd of this water could be used for irrigation, municipal, or industrial purposes, although only 100 mgd might be available for municipal and industrial uses during the crop season.

Barrier Dam

A barrier dam was proposed by the senior author in January 1957 as a means for supplying northern Delaware with abundant water and at the same time protecting the water-bearing sands of Delaware and New Jersey from salt-water encroachment along the Delaware River. (Salt-water encroachment has occurred as far north as Camden, N.J.) This proposal was mentioned in an intramural report prepared for the Corps of Engineers and distributed by them to State and other governmental officials in June 1957. A map of the plan is shown on the adjacent figure, which was plate 6 in that report. The proposal called for a low-level barrier dam across the Delaware River that would create a huge fresh-water lake, "Lake Delaware."

The illustrated damsite is at the river crossing of the Merchantville Formation and Woodbury Clay and would impound roughly 250 billion gallons. The entire intake area of the nonmarine Cretaceous sediments would be shielded from salt-water encroachment. The reservoir stage could be maintained at a level between 4 and 6 feet above mean sea level, so that the land would not be flooded to any greater



Barrier dam "Lake Delaware" showing locks and canals.

extent than is now experienced from the higher tides on the river. The reservoir so created would be about 60 miles long (from Delaware City, Del., to Trenton, N.J.) and would have an average width of 1 mile. It would have a maximum depth of about 50 feet and an average depth of about 25 feet.

Proponents of this plan, led by Brigadier General (ret.) Norman Lack, have chiefly been officials of the State of Delaware. They contend that in the near future the demand for fresh water will be enormous and of prime concern.

Among many opponents to the plan were the shipping interests of the ports of Philadelphia and Camden and the officials of those cities. They felt that ships passing through locks, either in the face of the dam or along bypass channels, would cause undesirable and costly delays and that the trade of those cities would dwindle. Wharves would require adjustment to pool stage. Flood discharge down the Delaware River, such as occurred in 1955 during hurricanes Connie and Diane, might back water to a higher stage than any previously experienced. The sanitary discharge from the cities would have to be carried in separate canals to avoid fouling the lake. Discharge below the dam would make the river intensely foul at that point. Biologists showed concern for the complete change that would occur in river regimen and in habitat for fish and shellfish.

Despite these disadvantages, the barrier dam would emplace tremendous volumes of fresh water at the north gate of Delaware and in adjacent Pennsylvania and New Jersey, an advantage that might eventually have overwhelming appeal. Furthermore, this approach underscores the claim of the people of the State of Delaware to some fresh water from the Delaware River. During the past 50 years industrial and sanitary wastes from Philadelphia, Camden, and Trenton have rendered the water unusable, except for cooling, and have made it unsuitable for much of the once-abundant estuarine life. Although pollution undoubtedly has had a harmful effect, a gradual rise in salinity over the last 25 years—ascribed by some to a worldwide rise of sea level at a rate of about 2 feet a century—has been even more harmful.

Importing Water

Another suggested method of supplying water to Delaware is to construct a huge conduit, extending from the falls on the Delaware River above Trenton, N.J., through which fresh water would be diverted to northern Delaware. Depending, of course, on the quantity of water diverted, this approach could to a large extent assuage Delaware's thirst.

The flow of the Delaware River is controlled by the Delaware River Master, a deputy appointed by the Supreme Court of the United States, to regulate release of water from storage reservoirs on the upper Delaware (above Montague, N.J.) to maintain a basic minimum discharge at Trenton. The discharge has generally been sufficient to keep the Delaware River fresh as far south as Philadelphia, but below that point the river is fresh only during periods of higher discharge.

As an advisory government agency, the Interstate Commission on the Delaware (contracted name Incodel) was organized in 1936 with five members each from Delaware, New Jersey, New York, and Pennsylvania "for the purpose of entering upon a program . . . to develop integrated plans to conserve and protect the waters and other resources of the Delaware River Basin." Incodel was discontinued in 1962 when the Delaware River Basin Commission, composed of Federal and the four State governments, began the work of focusing all major water resource activities in the basin under its authority, uniting and coordinating a valleywide assault on the many problems.

In 1959, the Corps of Engineers, which completed a 3-year, $2 million survey of the water resources of the Delaware River basin, reported to the Congress of the United States "the best plan for the conservation, control and use of the water resources of the Delaware River basin." In this plan the needs of the State of Delaware are integrated with the needs of the basin.

There are other streams in adjacent Maryland and Pennsylvania that might be used to supply the water needs of northern Delaware. The Susquehanna River has been mentioned as a possible source, but the recent move by the city of Baltimore would seem to establish a prior claim. Big

Elk Creek and Little Elk Creek in adjacent Cecil County, Md., have been considered as possible sources, but interstate negotiation is required before they can be used. In the increasing competition for water, the industries or municipalities involved will probably act to import water as soon as their needs are known.

Network of Wells

The 12 ground-water reservoirs will not be managed efficiently as sources of water until the water level in each one is periodically lowered by amounts so substantial that the natural discharge is cut off. Only by alternate withdrawal and recharge can any reservoir, surface or ground, be used at optimum efficiency. At present, our ground-water reservoirs are, in general, underdeveloped as supplies of ground water. Locally, however, they may be well developed or even overdeveloped.

To develop a ground-water reservoir to its maximum capacity requires a network of wells, spaced in a rational pattern based on the size and shape of the reservoir, the rates of transmissivity, the total amount of storage, and the areas and quantities of recharge and of competitive discharge. At present, our individual wells and our well fields have been placed chiefly as needed in proximity to the points of use.

We are in no position as yet, and will probably not be in position for some time, to determine a rational spacing of wells because we still have only "reconnaissance" information on the characteristics of the aquifers. Water from a network of wells derived from one aquifer would presumably be pumped to one or more storage or treatment tanks before distribution to consumers.

The annual quantity of ground water pumped could not exceed the normal quantity of rejected recharge without taking water from storage. Although some water could be taken from storage each year for a period of years, the water must not be allowed to fall to the level where the natural rate of transmission would diminish lest the operation be throttled. When this operating level is reached, the amount taken will have to equal the annual recharge less the natural discharge. This rate, or annual quantity, is called the "perennial yield" or the "safe yield." Many observation wells would be necessary to monitor the water level and water quality in the network of wells in an aquifer system.

In 1957 about 18 billion gallons of ground water were pumped in Delaware. However, the annual ground water discharged is estimated at 681 billion gallons, so the amount used represents only 3 percent of the total available. Even if only half of this rejected recharge should prove to be recoverable by properly spaced wells, the resulting yield is large—340 billion gallons. This yield is equivalent to 930 mgd, compared to 50 mgd used in 1957. A network of wells would therefore provide abundant water; however, the maintenance, the distribution lines, and the temporary storage facilities would be no small undertaking.

Artificial Recharge

In areas where nature does not adequately replenish the ground water withdrawn from the reservoirs, artificial recharge has been used with considerable success and at moderate cost. This method has been particularly successful in the arid West, where water is at a premium and the cost is justified. The method has also been used in the East—on Long Island, N.Y., and at Perth Amboy and Seabrook Farms, N.J. Newark, Del., is investigating the feasibility of recharging the sands of their north basin with runoff from storm sewers. The methods of artificial recharge, which requires a dependable water source, utilize either input wells, check dams, infiltration canals, spreading basins, or sprinkler systems.

The use of input wells is common on Long Island, where the return of cooling water to the water-bearing formation is required by law. One input well is required for each air-conditioning source well. The water circulates in an air-tight system and is returned to the ground unaltered except for a slight rise in temperature. This regulation was considered (but not adopted) by the city of Dover, Del., a few years ago because of declining water levels in the Cheswold aquifer.

Perhaps one of the most practical means of artificial recharge on the Coastal Plain of Delaware is to build a low dam on each surface stream just below the outcrop of the aquifer and induce more water to move downdip beneath the confining beds. The mill ponds function in much the same manner, for they are low check dams that locally build up the water table. For more than 50 years, Runyon pond at the Perth Amboy Water Works in New Jersey, about 80 miles north of Delaware, has been used as a spreading basin to recharge the Raritan Formation. Similar spreading basins would serve in places in northern Delaware where demand is exceeding storage capacity.

Infiltration canals offer a means of inducing waters, such as a part of flood runoff, to serve as recharge rather than flow to waste. These canals could be located over permeable aquifer systems, such as the buried channels of Pleistocene age in northern Delaware.

Sprinkler systems have been used for effective recharge at Seabrook Farms, N.J., of Coastal Plain aquifers similar to those in Delaware. The water supplied is waste water from a vegetable-processing plant.

Treated sewage water has been used for artificial recharge outside Delaware, but difficulties with pollution by detergents have been experienced in places. The detergents pass through the sewage treatment and then cause foaming in the recharge area.

Conservation of Water

Considerable waste of water often occurs in certain industrial plants where moderate water-saving practices are not used. The extent to which water-saving practices can be carried on will depend on the costs involved and the availability of water. For example, an integrated steel plant ordinarily uses 30,000 to 65,000 gallons of water to produce 1 ton of finished steel, but at the new Fontana plant in water-short California this amount was reduced to about 1,400 gallons per ton. Also, the petroleum-refining process ordinarily uses 18 to 34 gallons of water to produce 1 gallon of refined oil; in water-short areas, however, less than half a gallon of water may be used. Similar conservation practices can be effected, when necessary, in many other industries. The resultant saving would be of tremendous importance, as industrial use of water in this area is becoming a large part of the total water used.

Undoubtedly, considerable waste occurs in communities where unmetered water is used. Metering water sometimes reduces consumption by as much as 25 percent and, when readings are unduly large, leads to the search for and repair of leaks. Although metering introduces many additional costs, such as meter reading, repairing, and billing, it is usually more economical and certainly reduces waste.

The greatest waste of water in Delaware is due to transpiration by plant life of low economic value and to evaporation from marshes, bogs, and seepage faces. The peculiar "bay and basin" landforms described and low-lying coastal areas are conducive to large evapotranspiration loss. These high losses could be put to more economical and beneficial use in some parts of these areas by land-leveling operations and subsequent reforestation with trees of commercial value or by placing the land in cultivation; these suggestions are but two of many possibilities. A new idea is to salvage water, now evaporated and transpired, in humid areas like Delaware, and it holds real promise for the distant future.

Desalting Water

In recent years, public and private enterprises are attempting a major breakthrough in development of processes to desalt mineralized water. The Office of Saline Water was established in the Department of the Interior in 1952 and authorized by the Congress of the United States to expand research and to provide for the selection of sites and processes for five demonstration plants.

Fresh water generally costs 5¢ to 50¢ per 1,000 gallons to produce from normal fresh-water sources. In areas where only mineralized water is available, the cost of desalting must compare favorably to the cost of hauling fresh water in by truck, railway tankcar, barge, or pipeline in order to be competitive. Four methods are feasible in the laboratory: distillation, ion exchange, electrodialysis, and freezing. The problem is to make these processes practical and economically feasible on a large scale.

Distillation has been used to purify mineralized or polluted water since the 17th century, when a pure water is required or when no other source is available. Distillation has been costly chiefly because of the cost of heat required to vaporize the water, the cost of removing remnant brine, and the cost of power required to circulate water for the cooling coils. Newer methods offer promise of producing water by distillation at lower cost in water-short areas. The Congress of the United States has authorized two sea-water distillation plants for pilot demonstration, each having capacities of 1 million gallons a day. The first, a long-tube verticle multiple-effect distillation plant, is in operation at Freeport, Tex., on the gulf coast. The second, a multistage flash distillation plant, is operating at San Diego, Calif., on the west coast.

A third distillation plant, using a vapor compression process, went into operation July 1, 1963, at Roswell, N. Mex. It is designed to produce 1,000,000 gpd from ground water containing 24,470 ppm dissolved solids, about 70 percent the content of sea water.

The use of a low-cost solar-powered still has been a dream only now nearing realization. There is promise of producing pure water at 50 to 75 cents per 1,000 gallons by using nuclear-reactor steam to distill mineralized water.

Ion-exchange resins have successfully desalted water in the laboratory, but the problem of backwashing the resins seems insurmountable in practical operation. The principle is one in which ions are exchanged through several steps until the cations are eventually exchanged for oxonium ion (hydrated hydrogen ion OH_3^+) and the anions are exchanged for hydroxyl ion (OH^-). The oxonium and hydroxyl ions combine to yield water. When the filter resins are exhausted, they can be restored by backwashing, but the quantities of wash water required are nearly equal to those produced. Acids and bases that could be used for backwashing are relatively expensive.

Electrodialysis, a process of filtering water by using semipermeable membranes through which ions of salts diffuse, is very promising. The Bureau of Reclamation has operated a test plant in Webster, S. Dak., giving 25,000 gpd at $1.40 per 1,000 gallons. The first water-desalting plant in the United States to serve an incorporated municipality has been built in Coalinga, Calif., and uses the electrodialysis principle. The plant reduces dissolved-solids content from 2,000 to 300 ppm, producing 28,000 gpd at a cost of about $1.45 per 1,000 gallons. Ionics, Inc., has built and is building plants of this type in several parts of the world.

A freezing process has yielded 15,000 gpd in a pilot plant built by the Carrier Corp. at Wrightsville Beach, N.C., for the Office of Saline Water.

A research and development station of the Office of Saline Water at Wrightsville Beach, N.C., has tested several processes of desalting water. Its annual report issued in 1963 indicated that under conditions normalized to a scale of 14 million gpd multistage flash distillation could produce water at 45.1 to 59.6 cents per 1,000 gallons. This compares with 12.3 cents per 1,000 gallons as the average cost of public water supplies according to a recent survey by the American Water Works Association.

Clearly then, methods of desalting mineralized water are already in operation on a small scale, and research is gradually reducing the cost. Perhaps these methods eventually will be used in Delaware.

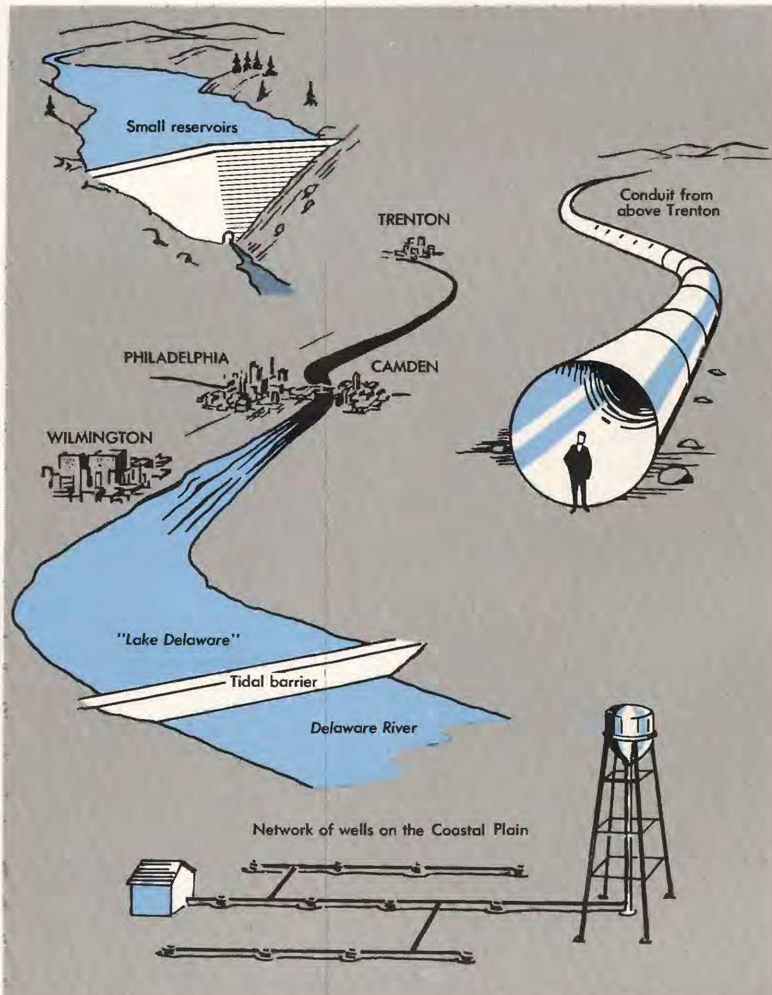
What Can We Afford?

Water is a major natural resource of Delaware. We have it in abundance and, in places, in superfluity. Yet, it has a price, which we are not always willing to pay. For many years we have taken cheap water for granted. Cheap water is still available at most locations, but it is not everywhere of a quality suitable for all purposes.

In the years to come water will increase in importance in the economy of Delaware. Industries, cities, and irrigated farms will use more of the available supplies. Competition for the least expensive water will be keen, but there is enough to go around if all sources are utilized in a practical manner.

This abundance of water should be no cause for complacency, however, for the Corps of Engineers Report on the

Delaware River basin states that the Wilmington area will have to import about 500 cubic feet per second (323 million gallons per day) by the year 2010. If a lake should be created behind a barrier dam on the Delaware River, there obviously will not be a need to import water at Wilmington. However, it may be more economical, or consonant with other interests, to pipe water in from many small reservoirs, from well fields on the Coastal Plain, or from the Delaware River or other rivers by conduit. These alternatives are shown schematically on the figure below.



Alternative solutions to the water problems of Delaware.

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