What's Happening to Water?[1]

By CHARLES J. ROBINOVE
U.S. Geological Survey, Washington, D.C.

[With 1 plate]

What is happening to water? In the early days of the United States, when the population was small and widely scattered, water was not a problem. Most people took water from streams or from dug wells for their personal use or for town distribution systems. Waterpower developments were made on streams in which water wheels could be run for mills. The total use of water in the United States and the average use per individual were not high, and the demands upon the total water supply of the country were small. The problems of water supply through the 19th century were not great—enough water was available for most users. If the supply might be short in one area, it could be supplemented from another; if the quality of surface water was poor for a particular industry, the ground water in the immediate area might be usable.

Since that time the American way of life has changed. Water is used for countless purposes, many of which were not dreamed of 50 years ago. The same water may be used over and over again in processes where it is not consumed, such as waterpower or cooling, or it may be consumed by irrigation or industry.

Today, the problems of water and water conservation are paramount in the minds of many people in the United States. Large organizations, both within and outside the Government, are concerned with the investigation of water resources, the development of water, and the proper management of water. More and more we hear that water is the "limiting factor" in developments of irrigation, industrial, waterpower, and municipal projects. It is apt to quote here the words of Oscar E. Meinzer, who, in an article entitled "Our Water Supply" in the 1937 Annual Report of the Smithsonian Institution, said, "Deprived of water, all plants and animals would perish.

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[1] Publication authorized by the Director, U.S. Geological Survey.

Deprived of water, the human race, with all its thought and emotion and spiritual aspiration, would come to prompt oblivion."[2]

The American people have become alert to the importance of water in our life and economy. The news media—television, radio, and newspapers—carry stories about pollution of streams, falling water tables, short supplies of water, and the decreasing number of sites left for major waterpower development. Stories are calculated to awaken the reader to the problems of water in the United States and to his responsibility to be aware of these problems and to take part in their solutions. In many instances the stories are exaggerated, but the problems are real.

In 1960 nearly 270 billion gallons of water per day, or about 1,500 gallons per day per person, was used in the United States (MacKichan and Kammerer, 1961). Of this total, 61 billion gallons per day was consumed and was not available for reuse. The estimated and projected withdrawals of water from 1955 to 2000 indicate that in 1980 our use of water will be more than double that in 1960 (fig. 1). The estimates for 1980 and 2000, however, may be greatly in error if reuse of water is practiced more widely and intensively than it is now.

The water that we use comes from many sources which may be shown as parts of a general picture of water movement on the earth.

THE HYDROLOGIC CYCLE

The major reservoirs of water on the earth are the oceans, and they form one link in what is known as the "hydrologic cycle." The hydrologic cycle describes the circulation of water from the ocean into the atmosphere; the movement of atmospheric moisture across oceans and over the continents; the precipitation of moisture as snow and rain; the flow of water in streams and lakes; the evaporation and transpiration of water from the surface back into the atmosphere; the movement of water beneath the surface of the ground; and the discharge of water back into the ocean to continue its endless journey. The hydrologic cycle is continuous and cannot be easily separated into its various phases, and in turn its phases are made up of endless and complex details. Water in any one phase of the cycle cannot be treated as a single subject. It must be considered in relation to its total natural environment, to its use by man, and as a function of time.

Let us begin by considering the moisture in the atmosphere. Water evaporates from the surface of the ocean. It rises in the air and is borne by winds over the landmasses, where a part of it condenses and falls as rain or snow. In the western United States most moisture is brought from the Pacific Ocean and carried east. When winds from the Pacific Ocean meet the west coast, the warm moisture-laden

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[2] Meinzer, O. E., Our water supply. Ann. Rep. Smithsonian Inst. for 1937, p. 292, 1938.

air is lifted high over the mountains and becomes cooler. The cool air cannot contain as much water vapor as warm air and so the moisture falls as rain or snow on the western slopes of the coastal ranges and the Sierra Nevada. East of the coastal ranges and the Sierra Nevada the air is drier; there is less moisture to precipitate and fall; and as a result, the region between the coastal areas and the Rocky Mountains is arid or semiarid. The lifting and drying effect of the continental mass is again shown as the air reaches the Rocky Mountains. Precipitation is greatest on the western slopes of the Rocky Mountains; the drier air moves across the mountains to the eastern slope, where the precipitation is less.

Precipitation in the central part of the United States increases as additional air masses moving from the Gulf coast, the Atlantic, and the Arctic region bring moisture-laden air over the continent.

Water is abundant in the United States. If all the precipitation that fell within the limits of the 48 conterminous States during an average year were to be spread evenly over the country, it would stand 30 inches deep. However, as the pattern of air movement indicates, this precipitation is not spread evenly over the United States. Some areas receive only a few inches of rainfall during the year, while others receive as much as 100 inches.

The water represented by the average 30-inch depth is about 4,800 million acre-feet per year, or about 4,400 billion gallons per day. This is an enormous amount of water, but unfortunately not all of it is available for our use. Of the 30 inches of water, about 21½ inches is evaporated from open water areas or is transpired from the soil and the leaves of plants and thus returned to the atmosphere. Only part of this 21½ inches supports cultivated crops, native grass, and forests; the rest is evaporated or used by nonbeneficial plants.

The remaining 8½ inches of rainfall moves over the ground to streams as "direct runoff," or seeps to the water table to become "ground water," later to discharge into streams as "ground-water runoff." Of the 8½ inches, man withdraws from streams, lakes, reservoirs, springs, and wells the equivalent of about 2 inches (but in part this represents the same water used over again) and uses it for municipal and rural water supplies, industry, and irrigation. About half an inch evaporates or is transpired, in part as a result of the activities of man (principally irrigation) and in part by natural means in the Great Basin. The remainder joins the "unused" water to make a total of about 8 inches flowing into the oceans. Actually, the "unused" water is used too, though not "withdrawn"—for hydropower (to an extent equivalent to nearly twice the average streamflow), for dilution of sanitary and industrial wastes, for navigation, and for recreation and fish and wildlife.

The general disposal of the 30 inches of precipitation received is shown diagrammatically on plate 1, in which the quantities are rounded off to whole numbers.

The 8½ inches of runoff represents, virtually, our manageable water supply. Management of water consists of solving the general problem—national, regional, or local in scope—of how to obtain perennial supplies of water of usable quality at a reasonable price at desired locations for specific uses. Each area of the Nation has several water problems that require solutions, and these may differ greatly from those in other areas of the country.

WHAT WE KNOW OF THE HYDROLOGIC CYCLE

Much is known about the fundamentals of hydrology and the laws that govern the occurrence and movement of water on and below the surface of the earth. Research directed to finding these facts has been a continuing and accelerated program throughout the United States and elsewhere and has been carried on by governmental agencies, universities, and foundations. A great deal has been learned, but a great deal more remains to be understood.

The mechanics of precipitation of water from atmospheric vapor as rain, hail, and snow is fairly well known. However, we still do not understand the distribution of precipitation in time and space well enough to predict how much rain or snow will fall where and when—to say nothing of being able to influence them. Stations for the recording of precipitation and temperature are scattered throughout the United States, but most of them are in heavily populated areas. However, much of the precipitation falls where the population is small and scattered, such as the mountainous areas of the West, which furnish a large part of our water, and records from these areas are spotty and inadequate. More has to be learned about the distribution of precipitation in these areas before we can understand and predict our primary source of water (Langbein and Hoyt, 1959, p. 41).

When water reaches the land surface, a portion soaks into the ground and is stored as soil water which is available for the growth and nourishment of plants. This zone of soil moisture may at times be completely saturated with water—that is, all the pore spaces between the grains of soil and rock may be filled with water, or they may be only partially filled. We need to know more about the mechanism of the filling and draining of the soil-moisture zone. We also need to know a great deal more about how much water is extracted by crop plants and native plants from this soil-moisture zone and how much water is evaporated from the land.

Between the zone of soil moisture and the water table is the zone of aeration. Water in excess of the amount ("field capacity") that the soil can hold moves downward under the force of gravity. The mechanics of the movement of water in this zone are complex and not so well understood as the movement of water in some other phases of the hydrologic cycle. Because water must move through this zone, which is not saturated with water, in order to enter the saturated zone where the ground water moves laterally through completely filled pore spaces, further research on the mechanics of water movement in the zone of aeration is essential.

Fluid movement in the zone of aeration involves movement in three phases; water, water vapor, and air. Water is retained in the zone of aeration as films of water surrounding particles of the rock or completely filling some of the void spaces between the grains. Water completely filling the voids can move downward until it reaches the water table as ground-water recharge. Downward movement of water in the zone of aeration is primarily in the water phase; the transfer of water vapor does not contribute significantly to ground-water recharge.

A particular ground-water reservoir, such as the Dakota Sandstone of the northern Great Plains, may underlie tens of thousands of square miles, while another ground-water reservoir, such as the sand beds underlying Long Island, may be confined to relatively small areas. The movement of ground water in small aquifers (water-bearing beds or strata) may be only part of a large pattern of ground-water movement throughout a larger area. The effects of water use and development must be studied in both large and small areas in order to understand fully the regimen of ground water.

Water moves through ground-water reservoirs until it is discharged as springs, by seepage into streams and lakes, and through withdrawal by man. Such discharge allows a continual movement of water through aquifers and provides room for recharge. The amount of water moving through the ground and the total amount of water removed from the ground-water reservoir in any specific period of time are known only approximately. The water that seeps into streams and lakes provides the base flow of the streams—that is, the low flow that is sustained through the driest part of the year. If water is diverted from a ground-water system and withdrawn for use, such as irrigation, or the water is evaporated back into the atmosphere, the base flow may be reduced substantially or even eliminated. The complex interrelationship of water on the surface and under the ground is one part of the hydrologic cycle which we need to study more intensively in order to make the best use of both sources of water.

Evaporation and transpiration are two phases of the hydrologic cycle that are difficult to study quantitatively. Only in the last few years have instruments and mathematical techniques been developed to measure and calculate the rate and amount of evaporation from open water and land surfaces and the transpiration of plants. Evaporation may be estimated by measuring the loss of water from open pans on the land surface, but application of the evaporation rates to lakes and swamps can be misleading. Recent studies of energy budgets and heat transfer provide more reliable means of calculating total evapotranspiration than we have had in the past. In the future we may look to measurement of atmospheric moisture at elevations high above the ground and to the use of instruments carried in aircraft to give us gross figures on the total evaporation from a particular area.

The water on and below the surface of the ground is not pure; it contains varying amounts of different chemical substances in solution. The amount of material that is carried in solution by the water depends upon the solubility of the rocks with which the water comes in contact and the length of time of contact. Research into the physical and chemical properties of water and rocks and the interrelations of the water and the dissolved mineral matter are of extreme importance because of the uses to which we put water. Industries, municipalities, and irrigation all require water that is within certain but different limits of chemical quality. Ground water at a particular place generally has a fairly constant chemical quality, but water in streams in the same area may vary greatly in chemical quality during the year. The constancy of ground-water quality is an attractive feature for consumers whose water-quality requirements are not flexible.

WATER PROBLEMS OF THE UNITED STATES

It is easy to see that we cannot manage water as a whole throughout the Nation, because water problems are not the same everywhere. We have therefore oversimplified the major water problems in the following discussion. The general problem of water in the United States can be broken down into six problems of major importance which plague the Nation's water resources. Plate 1 shows the major areas affected by the problems listed.

The first problem, and one that comes most quickly to mind, is that of deficient supply—not enough water. Deficient supply is primarily a problem of the southwestern United States, although, as with other problems, it occurs in some areas elsewhere. In such areas, the total supply of water is not sufficient for the demands made upon it. Deficient supply may be in part an economic problem. Water may be available, but the cost of obtaining it can be prohibitive.

The Navajo country of Arizona, Utah, and New Mexico covers about 25,000 square miles and is a good example of an area of deficient supply. It is sparsely settled and probably never will have the problems of an increasing population similar to those of the nearby cities of Phoenix and Tucson. Nevertheless, a stable water supply is needed for those who live and work in the Navajo country. Few streams are perennial—the Colorado and San Juan Rivers on the west and north sides of the Navajo country are the principal exceptions, but water from these generally is not available because the streams are deeply entrenched in canyons and the water contains large amounts of sediment. The meager supplies on the reservation come from small and undependable reservoirs on intermittent streams and deep but dependable wells. On an average, only about 10 gallons of water per day is available for human consumption (U.S. House of Representatives, 1953, p. 126). A larger and more dependable water supply can be assured only by a program of storage of runoff, promotion of the growth of plants that would use less water or be of more economic value than the present native species, and use of the ground-water reservoirs to the maximum capability, if such is economically feasible. Such a program would be expensive and would require more information on the Navajo country than is now available.

The second major water problem is that of variability. The available water supply may be less than the demand during drought years and greater than the demand during wet years. The average water supply may be able to meet the average demands, but this statement is small consolation to a user of water who must face several years of drought during which he cannot get enough water to meet his needs. This problem gives rise to the often asked question "Is our total water supply decreasing?" The answer to this is "No!" We may have less water at a certain place at a particular time but at other times we may have more water than we can use. Thus, droughts have been of serious proportions in the Central Plains in the 1930's and in a large part of the country in the 1950's, but at other times these regions have had surpluses of water.

Water supplies vary throughout a single year also. Irrigation in the West demands large and dependable water supplies during the growing season, but the natural stream runoff varies greatly during that time. Storage of surface water in reservoirs to regulate the flow for irrigation, together with the use of stored ground water, can even out the usable supply and allow its release when needed.

The distribution of the water supply is the third problem of major importance. The distribution problem means that the supply exceeds the demand in one part of a region and is less than the demand in another. For example, northern California has large supplies of water and the demand for water is small; southern California, in contrast, has a limited supply but its large, ever-expanding population and industry need ever-increasing amounts of water.

The Los Angeles River furnished the municipal water supply for the city of Los Angeles from the founding of the city in 1781 until

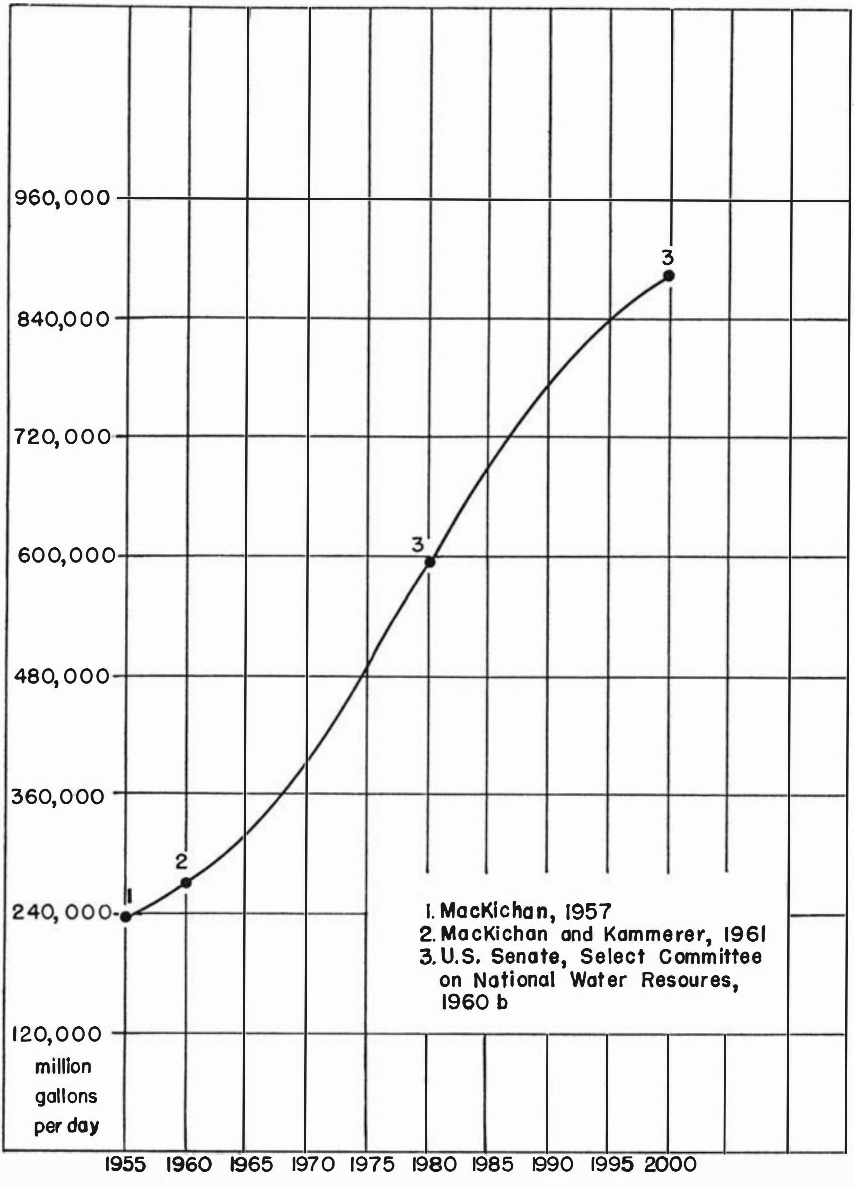

FIGURE 1.—Estimates of total withdrawals of water (excluding waterpower), 1955–2000.

1913. By 1900 the local water supply was obviously going to be inadequate for the anticipated population growth, and other possible sources of supply outside the local area were investigated. As a result, a 215-mile aqueduct was built to import water from Owens Valley on the east side of the Sierra Nevada. By 1930 the population of the coastal basins near Los Angeles had increased to over 2½ million. To supply the growing population, the Colorado River was tapped and an aqueduct, 240 miles long, with a capacity of 1,500 cubic feet per second of water, was constructed by the newly formed Metropolitan Water District of Southern California and began delivery of water in 1941. The Metropolitan Water District now supplies water to Los Angeles and surrounding cities with a combined population of over 7 million and also supplies water to San Diego County.

At present the State of California plans to store and divert water from the upper Feather River drainage area in northern California for use in the Central Valley, San Francisco Bay area, and southern California. The magnitude of these efforts to provide water for municipal and other uses is testimony to the expense and effort needed to adjust the natural distribution of water to sustain the life and economy of southern California.

In many regions the quality of water is the fourth major water problem. Water quality is determined by the dissolved chemical constituents and by the sediment carried in the water. The chemical quality of water is extremely variable, and in some parts of the Nation the water has always been "poor"—that is, unusable for most purposes because it contains excessive amounts of dissolved minerals. Much of the water in the ground is of poor quality—possibly more water of poor quality than of good quality is stored in the ground. A person may say that his water is 99$^{44}\!/_{100}$ percent pure, but such a statement is only figurative. The amount of dissolved minerals in natural water is measured in p.p.m. (parts per million), that is, parts of mineral constituents per million parts of water. A water that could be said to be "99$^{44}\!/_{100}$ percent pure" would contain 5,600 parts per million of dissolved mineral matter and would be unfit for drinking. Drinking water usually should have no more than 500 p.p.m. of dissolved minerals. Sea water usually is about 96½ percent "pure."

Sea water may mix with surface and ground water and thus impair the quality of the fresh water. The sea water off the coast opposite New York City has a normal chloride content of about 18,500 p.p.m. The tidal estuaries of streams flowing into the Atlantic Ocean near New York City have somewhat lower salinities, from about 2,000 to 16,000 p.p.m. of chloride, because the fresh water of the streams is mixed with the sea water. The ground water in parts of Queens

County, Long Island, is fresh and contains less than 100 p.p.m. of chloride. In parts of Kings County and southern Manhattan, however, the chloride content of the ground water has become as high as 15,000 p.p.m. This indicates contamination of the fresh ground water by encroachment of sea water (Perlmutter and Arnow, 1953, p. 37). Pumping of fresh ground water may cause a reversal of the gradient of the fresh ground water, which usually moves from the high land areas to the ocean. The reversal of the gradient allows the sea water to enter the fresh ground-water reservoir.

A large body of salty ground water beneath southwestern Nassau County and southeastern Queens County, Long Island, probably is encroaching landward at a rate somewhat less than 100 feet per year (Perlmutter, Geraghty, and Upson, 1959, p. 417).

Salty ground water cannot be used for municipal water supply, but it can be used by industry, principally for cooling and air conditioning. The problem of continued encroachment of sea water can be and is being solved either by reducing the total amount of ground water pumped or by pumping the water out of the ground, using it for cooling, and pumping it back into the ground. This recirculation is a water-conservation measure that can reduce the total amount of water removed from the ground-water reservoir and thus slow down the rate of salt-water encroachment.

The sediment carried by streams and deposited in reservoirs also affects its quality. Although some waters have small concentrations of sediment, they may, because of the great total volume of water, carry a large total sediment load. A reservoir built on a river that has a large sediment load may eventually be filled with silt and other sediment and become unusable for further storage. Sediment is also a major problem to the operators of municipal and industrial waterworks, which must have facilities capable of removing sediment from water before the water can be used.

Some major reservoirs have lost sizable parts of their capacity owing to accumulation of sediment carried by streams flowing into the reservoirs. The sediment load of the Colorado River near the United States–Mexico boundary was 180 million tons per year before construction of dams on the main stem of the Colorado. After Hoover Dam and other dams were built, the sediment was impounded in the reservoirs instead of being transported to the delta at the mouth of the river. Lake Mead, the lake behind Hoover Dam, has filled with sediment at a rate slower than originally estimated, but reservoir capacity needed for storage of water has nevertheless been lost. In addition, the loss of the normal sediment load of the river below Hoover Dam has changed the regimen of the stream and allowed it to cut its channel deeper than if it carried its normal sediment load.

Natural water of poor quality must be distinguished from water polluted or contaminated by man and his agencies. The poor natural chemical quality of water is a problem that is not easily coped with, but a great deal can be done to avoid and correct pollution of water in streams and below the surface of the ground. Pollution, the fifth major problem, consists of permitting the entry into streams, lakes, and ground-water reservoirs of materials that are harmful and cannot readily be removed by normal water-treatment processes. These include organic and inorganic waste from municipalities and industries, which may, for example, temporarily lower the dissolved oxygen content of water in streams and lakes to a point where no fish or other aquatic life can live in the water.

Waste must be disposed of, of course, and disposal of waste into flowing streams has been a practical method for many years. However, the streams must have a large enough flow to dilute the waste, and when the wastes become a large enough percentage of the streamflow so that the quality of water is objectionable, the stream is polluted. The solution to the pollution problem lies in determining the best way of handling the waste material. We cannot stop waste disposal—we must learn to control it and perhaps handle it without having to use large quantities of water for waste dilution.

The Potomac River, which is the source of water supply for the Nation's Capital and other communities, has been polluted by the municipal and industrial sewage discharged into the river and its tributaries. Aquatic vegetation and fish cannot thrive in its polluted water. Recreational activities such as swimming and boating bring people into contact with polluted water, constituting a health hazard. The prevention of future pollution and the control of the present pollution are goals that can benefit all users of the Potomac. Steps have already been taken to cut down or eliminate the discharge of raw sewage into the Potomac River; many cities now treat the sewage before disposal.

The estuary of the Potomac is narrow and deep and extends from Chesapeake Bay upstream to Washington. The river in this estuary receives pollution from other streams flowing directly into it and from sewage of cities adjacent to the estuary. The large size of the estuary combined with a back and forth movement of tidal surges prevent the pollutants from discharging into the sea fast enough, and the pollutants are therefore concentrated in the estuary, raising the temperature of the water and increasing the concentration of organic material. Within a few years no raw sewage will be discharged into the Potomac, but the problem of concentration of pollutants may still remain. Perhaps it will be necessary to dispose of sewage without discharging it into the river. Pumping sewage into ground-water reservoirs has been suggested as a pollution-abatement measure along the Potomac.

Even if this proved to by hydrologically feasible, which is not likely, care would have to be taken to ensure that the ground water did not become polluted.

The sixth major water problem, that of floods, probably gains the greatest public attention because floods are often of disaster proportions. Floods are a normal part of a river's life. The flow of a river generally ranges from the low flow, which is maintained principally by ground-water seepage into the stream, to a bank-full stage which occurs on the average of about twice a year. Higher flows, which may occur about every 10, 50, or 100 years, depending upon local conditions, can only be carried outside the channel of the river on the flood plain. Floods can be controlled by the construction and use of water-storage reservoirs, which tend to even out the annual fluctuation to a more or less steady flow. However, the construction of reservoirs solely for flood control is not always economically practical, and for that reason multipurpose reservoirs must be designed. These can be partly emptied and used for storage of flood water, which is later released for hydroelectric power generation, navigation, irrigation, water supply, and the dilution of waste reaching the river downstream from the reservoir.

The extent to which floods can endanger life and damage property is well illustrated by the floods of August 13–19, 1955, on the eastern and northeastern coasts of the United States. Hurricane Connie crossed the coast of North Carolina at about noon on August 12, moved north along the coast, across eastern Virginia, northeastward across central Maryland, Pennsylvania, and the southwestern tip of New York, and entered Ontario on August 14. Scattered floods occurred as a result of this hurricane, but its most dangerous effect was to saturate the soil to its capacity, which meant that further heavy rains would cause high runoff. Three days later hurricane Diane crossed the southern North Carolina coast, moved northward across southeastern Pennsylvania, crossed New Jersey, and swept out to sea south of Long Island on August 19. Heavy rains occurred in a broad band along the coast, an area that includes the most industrialized and densely populated part of the United States. The ground, still wet from the rains of August 12–14, could absorb only a small part of the rain; consequently, the rest ran off in the stream channels and flood plains, causing disastrous floods. In spite of flood-control reservoirs, property damage amounted to almost $500 million, and some 200 persons were killed or injured. The floods reached new record maximum discharges at 129 of the 287 stream-gaging stations in the flood area (Bogart, 1960). Predictions of maximum expected floods are based on statistical analyses of the frequency and magnitude of previous floods, and the recorded data on such record-breaking floods as those of 1955 will make possible wiser planning of future flood control.

These, then, are the six major water problems of the country. Much is known about the natural regimen of water and about the effects of man's use of water, but nevertheless we need to know a lot more. The various water problems have been solved, in part and temporarily, in many ways. Technology can aid in the avoidance or correction of water problems; dams have been built to regulate river flow to alleviate floods, to provide water for consumptive use, and to furnish hydroelectric power; and municipalities and industries treat their sewage to prevent pollution. Water has been diverted hundreds of miles, even across the Continental Divide, to areas where natural water supplies are inadequate. But what will happen to water in the long run? How can we as a Nation use our water supplies wisely and with the greatest benefit?

CAN WE SOLVE OUR WATER PROBLEMS?

The solution or avoidance of water problems can be achieved only through sufficient knowledge of basic hydrologic processes, adequate basic facts on water occurrence throughout the Nation, and experience in dealing with water problems.

An understanding of the physical and chemical regimen of water is a prerequisite to the proper use of water and the correction or alleviation of water problems. The expression "balance of nature" is often used in the field of natural history and conservation to refer to the relations of living organisms with each other and with their environment. By analogy this expression is also applicable to the hydrologic environment when not affected by man. The amount of water in each of the phases of the hydrologic cycle is relatively constant over long periods of time of the order of thousands of years. For example, the amount of water discharging from a ground-water reservoir is equal to the amount of water entering the reservoir if no changes in the system are made by man.

Man's diversion and consumption of water upset the balance of the hydrologic cycle. Readjustment may take generations or even thousands of years. But the natural system must be thrown out of balance in order to provide water for man's use. Man must have water, but he must realize the consequences of water development in order to get the greatest benefit from his use of water.

There are three stages in the development of water resources of a particular area, whether it is a small drainage basin or the entire Nation. The first stage is use of the available water for needed purposes without planning or anticipating future expansion of water development and the consequent problems.

The second stage begins when problems such as deficient supply or pollution are seen to be serious. In this stage the problems are recognized and data on the hydrologic system are collected and analyzed to determine the best ways of furthering development of the water supply as well as of minimizing the problems. Development in the second stage usually consists of stopgap measures to alleviate the major problems—stopgap primarily because of economic and sociological limitations.

The third stage, water management, consists of comprehensive planning and development of an area's water resources with the goal of providing the greatest benefit from the water and the minimization of water problems. The knowledge of how to manage water depends on the results of research in the fundamentals of the hydrologic cycle. For example, we must know the amount of water interchanged between the land surface and the ground-water reservoirs through the zone of aeration. Research is put into practice in the description and appraisal of hydrologic systems in specific areas, such as Long Island, where surface water, ground water, and the ocean all must be considered in evaluating the availability and usability of water. Principles of water management are based upon the existing physical and chemical regimen of water and are modified as needed by economic, legal, and sociological factors.

The development of water can then be adjusted to an optimum level at which maximum usability of water is assured with a minimum of bad effects on the resource and the users. Facts and sound principles of water management are not enough, however, to make these adjustments effective. Experience in the utilization and management of water is an additional vital factor in the conservation of water which allows us to profit from our mistakes.

Water management, the ultimate step in the development of water resources, has not yet been reached for any area. As we develop the water resources of the country and pass through the various stages of development, we must recognize that management of water will become a greater and greater tool in the full development of the Nation. A "laissez faire" attitude of water use must be a thing of the past, and we must recognize our responsibility to manage our resources wisely.

If we could visualize an imaginary electronic computer programed with sound principles of water management, into which we could feed all the facts on the water resources of an area, data on the present and expected use of water, and the sociological and economic facts allied with the development of water, perhaps we could push a button and get the solutions to the water problems. Unfortunately, we do not have such a computer and maybe we never will have. But it is certain that the continuation of scientific and engineering studies of the basic principles of the hydrologic cycle together with complete appraisals of the available and usable water resources of the Nation can lead ever closer to the ultimate goal of water management and conservation for any area in the Nation.

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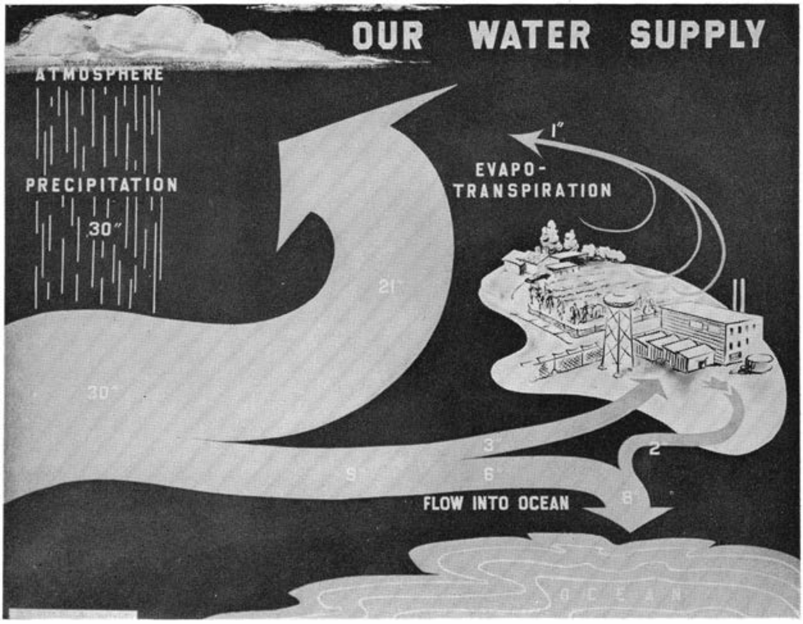
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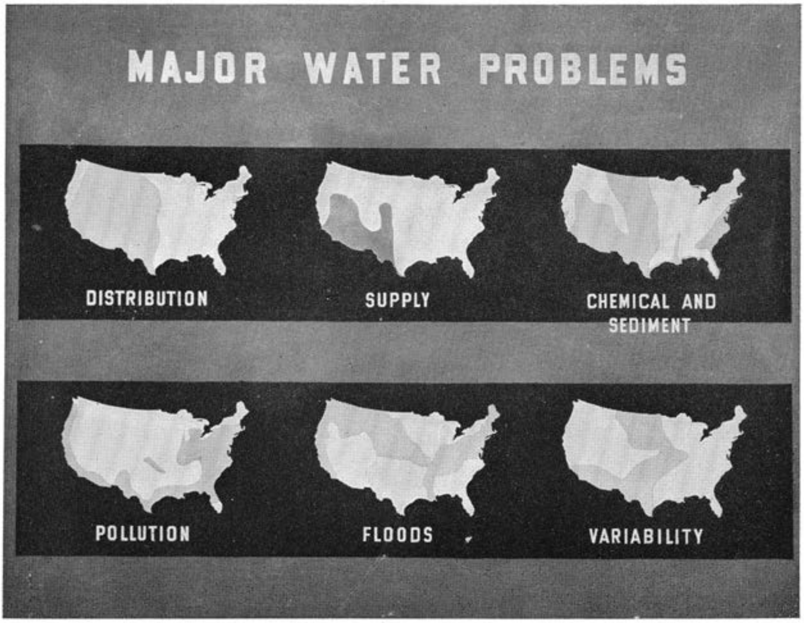
PRECIPITATION
30"
EVAPO-TRANSPIRATION
1"
21"
30"
3
9"
6
2
FLOW INTO OCEAN
8"
OCEAN


MAJOR WATER PROBLEMS
DISTRIBUTION
SUPPLY
CHEMICAL AND SEDIMENT
POLLUTION
FLOODS
VARIABILITY