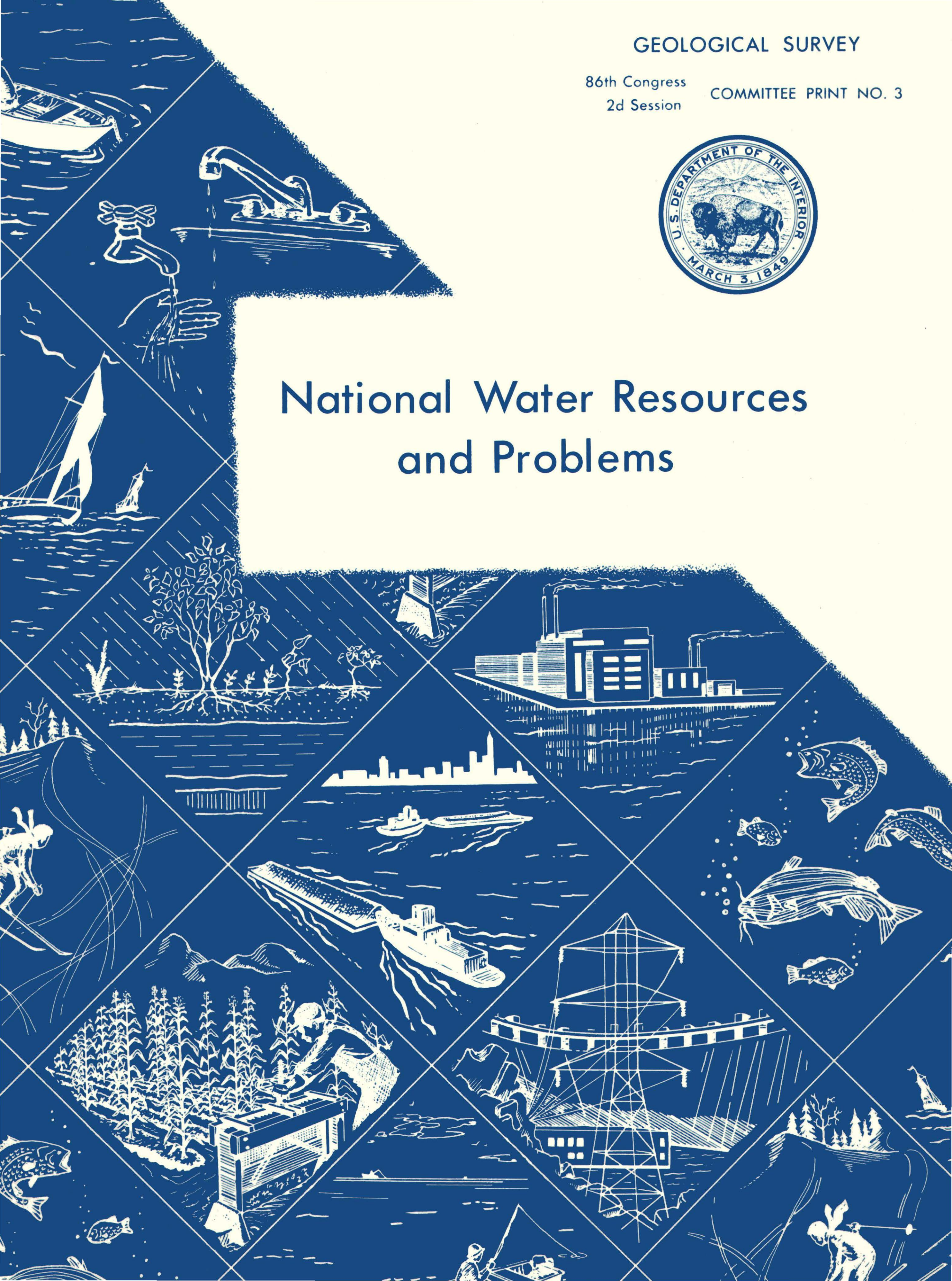
GEOLOGICAL SURVEY

86th Congress
2d Session

COMMITTEE PRINT NO. 3

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

National Water Resources and Problems



United States Department of the Interior

STEWART L. UDALL, Secretary

Geological Survey

THOMAS B. NOLAN, Director

This report was prepared by the Water Resources Division of the United States Geological Survey for the Select Committee on National Water Resources of the United States Senate at the request of Senator Robert S. Kerr, chairman. The report is a summary of the national water resources and problems of water use.

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86th Congress } 2d Session }

COMMITTEE PRINT NO. 3

WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

NATIONAL WATER RESOURCES AND PROBLEMS

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS

JANUARY 1960

Printed for the use of the Select Committee on National Water Resources

UNITED STATES
GOVERNMENT PRINTING OFFICE
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STATEMENT BY THE CHAIRMAN

JANUARY 11, 1960.

To the Members of the Select Committee on National Water Resources:

Among the basic requirements for our study under the provisions of Senate Resolution 48 of the extent and character of water resources activities required to provide the quality and quantity of water needed for all segments of our economy by 1980, are facts regarding the water supplies available to our Nation, and the problems experienced in their utilization.

In view of the wealth of data and experience on water resources and related problems accumulated over the years by the Geological Survey of the Department of the Interior, I asked the Director, through the Secretary of the Interior, for statements giving a quantitative and qualitative summary of the Nation's water supply, both surface and underground, the magnitude and character of present withdrawals and consumptive use, and problems associated with such use, including problems of waste disposal. In response to my request a report entitled "National Water Resources and Problems" was prepared by the Geological Survey. In addition to furnishing quantitative information showing water use, water availability, and amount of storage which will be required to maintain certain rates of riverflow, the report identifies and discusses water problems in six major areas; namely, supply, variability, distribution, natural quality, manmade pollution, and floods. The report indicates that almost every part of the United States faces current or potential water problems. The present water use of about 250 billion gallons of fresh water a day is estimated to reach about 600 billion gallons a day by 1980. However, less than a third of the water used at present is consumed, and with proper attention to pollution abatement the same water can be used over and over again. With a manageable supply of water of 1,160 billion gallons a day, the presently known problems can in general be solved, although some of the solutions may be costly. The report concludes with the finding that the United States has an adequate water supply if properly managed.

The Geological Survey was also requested to furnish data with respect to availability of water supply for various representative metropolitan areas within the water resources regions selected for use in the studies for the committee. Tabulations of these data are included as an appendix to the report.

In addition to furnishing background data for the technical studies being performed for the committee, the report will be interesting and informative to you, to the other Members of the Senate, and to others concerned with the Nation's water problems and their solution. Accordingly, I am having it printed as one of our committee prints dealing with the aspects of water resources activities which are being considered by the committee.

An additional report giving surface water supplies by States is also being assembled by the Geological Survey and will be printed separately.

ROB'T S. KERR, *Chairman.*
Select Committee on
National Water Resources.

COMMUNICATIONS

June 16, 1959.

Hon. Fred A. Seaton
Secretary of the Interior, Department of the Interior,
Washington, D.C.
(Attention: Mr. Thomas B. Nolan, Director, Geological Survey)

My Dear Mr. Secretary: The Select Committee on National Water Resources was established by Senate Resolution 48 of the 86th Congress, 1st session, and is charged with making studies of the Nation's water resources problems to form a basis for recommendations to the Senate on water resources policies for the future. The committee is cognizant of the wealth of studies and experience on water resources problems which has been accumulated by the Geological Survey over the years. As one of its first steps, the committee wishes to inform itself on the nature and scope of information already available on the water situation and water supply-demand problems of the Nation.

To begin the collection of such information, it is requested that brief statements on the following subjects be prepared by the Geological Survey. It would be highly desirable if these answers, none of which should exceed about 10 pages in length, with whatever tables, charts, or graphs are needed, could be furnished to the committee at as early a date as is practicable.

1. A generalized quantitative and qualitative summary of the Nation's surface water resources by river basins and by States, and in terms of drought years and average runoff years.
2. A statement on ground-water resources and use in the United States, by regions, with special reference to potentialities of the resource to help meet increasing water demands between now and 1980.
3. A statement on the withdrawal and consumptive uses of water, including data on use, quantity, quality, source, points of withdrawal, and trends in use, and giving information on how industry uses water, quality requirements for various purposes, and factors affecting the quantities used.
4. A statement on the effects of using surface and ground water for disposal of waste materials, including radioactive wastes, with information as to how such disposal affects the reuse of these waters for municipal and industrial development.

In making this request, the select committee wishes to indicate its confidence that the Geological Survey is extremely well qualified to discuss and comment on many of the most important aspects of the Nation's water resources problems.

Sincerely yours,

Rob't S. Kerr, *Chairman.*

Department of the Interior
Office of the Secretary,
Washington, D.C., December 31, 1959.

Hon. Robert S. Kerr,
U.S. Senate, Washington, D.C.

Dear Senator Kerr: I am forwarding the attached statement on national water problems which was prepared by the U.S. Geological Survey in answer to your request of June 16, 1959.

Sincerely yours,

Fred A. Seaton, *Secretary of the Interior.*

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NATIONAL WATER RESOURCES AND PROBLEMS

Introduction

Water problems exist in all parts of the United States. Furthermore, the problems are becoming more acute and widespread as population and industry grow. The need is pressing for wider appreciation of the nature of water problems. This requires a background of basic facts about the occurrence of water, its quantity and quality, and the manner in which it is used. This report records some of these basic facts.

The facts are that the United States as a whole is well endowed with water. Many water problems (which exist in our country) are caused, however, by poor distribution of water in time and place. Because the nationwide supply of water is large, any given locality could be supplied with water sufficient in quantity and suitable in quality, provided that those who need the water can pay the cost. For the most part, then, water problems are basically social and economic. Wise management is needed, both locally and regionally, with flexibility to respond to broad geographic patterns of economic and social development.

Major Water Problems

When good water is plentiful and cheap it is taken for granted; when it is poor in quality, costly, or scarce, everyone is concerned.

Use of water creates problems. For example, the natural flow of streams supplied sufficient water for early irrigation development in the West following the Civil War. But as irrigation increased, the need for water exceeded the natural streamflow without regulation. Then the farmer had an additional problem of obtaining water when the crops needed it. Storage reservoirs were constructed and water was stored at times of surplus and withdrawn when it was needed.

Problems other than inadequate supplies troubled pioneer water users of the West. Floods occasionally destroyed diversion works. In some areas, streamflow, though plentiful, had poor quality and use of it produced alkali deposits harmful to the soil. Problems of supply and quality are common to western water users—these problems and other kinds are troublesome in the remainder of the Nation

In the West, water problems also involve complicated legal questions relating to property rights in the use of water resources. These legal questions arise in many forms ranging from comparatively simple questions of priority to questions that are highly complicated by reason of potential Federal claims based on the reservation or withdrawal of lands for national purposes, particularly those for the national forests. Until this situation is further adjusted or clarified by Congress or the courts, many rights ranging from those of municipalities to those of individual irrigators which were believed to have rested under applicable State law or local practice will remain in doubt. These legal problems cannot be ignored. It is not intended that such problems relating either to western water rights and uses or to developments now taking place eastward shall be treated in this report. However, insecurity of rights to the use of water can have a serious impact on the ability of States and communities to finance needed water development.

Water problems may be classified in several ways. In this report they are identified as problems of supply, distribution, quality (chemical and sediment), pollution, floods, and variability. The maps in figure 1 show where each of these problems are serious. Every part of the United States has at least one type of major water problem. As the population and economy of the country grows, more and more water will be used and the problem areas will grow and the problems will become more acute. However, the types of problems will probably remain unchanged. In 1955, we used slightly less than 250 billion gallons of water per day, but by 1980 we will be using almost 600 billion gallons. The demand expected is shown in figure 2. Note that it is expected that the demand in the industrial East will increase faster than in the West where irrigation is the major water use. The greater increase

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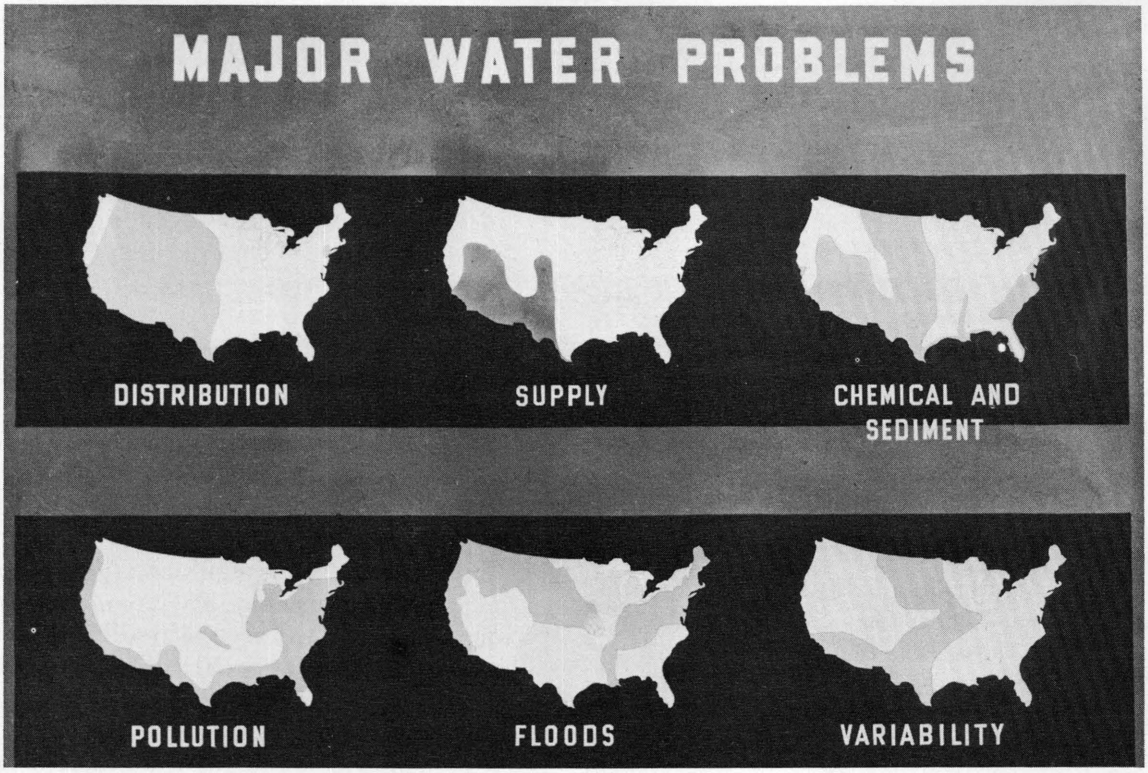

FIGURE 1

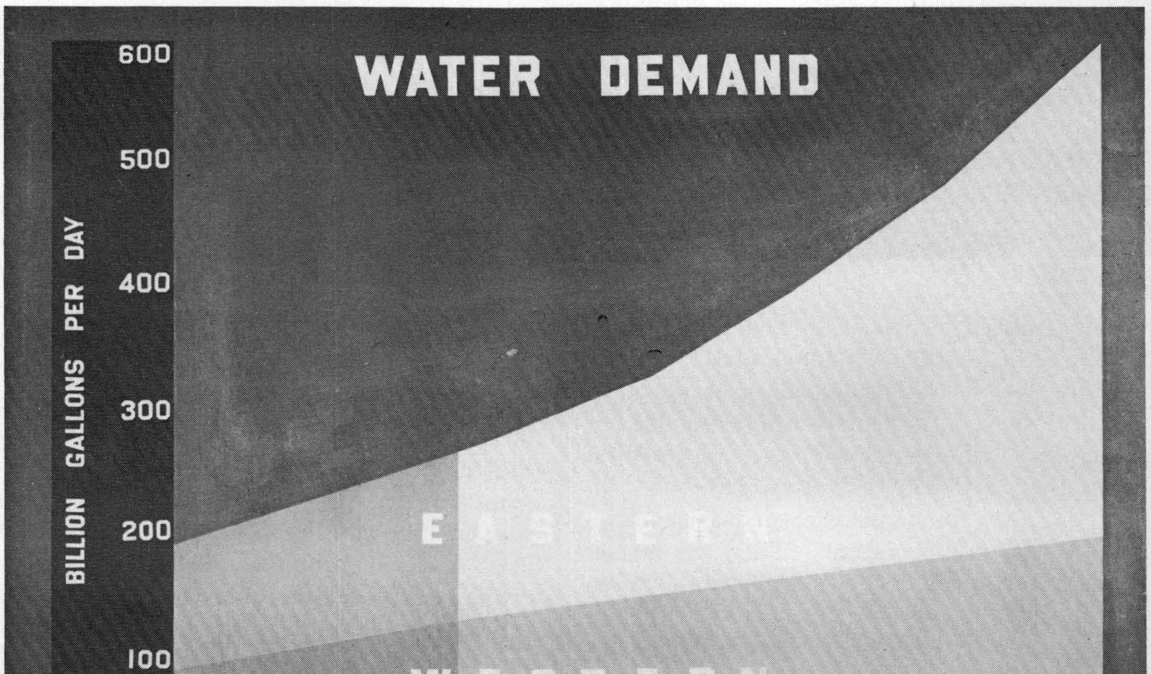

FIGURE 2

in water demand in the East is expected as a result of rapidly increasing population and industrial production.

WATER SUPPLY PROBLEM

Water supply becomes a problem whenever demand exceeds the available resource. As indicated in figure 1, supply is one of the major types of water problem. To understand the extent and importance of supply as a problem, it is necessary to compare the resource with demand. But first we must understand the nature of the resource and the demand.

Precipitation is the source of our entire fresh-water supply and for the Nation it is enormous. In a normal year the United States as a whole receives enough precipitation to cover the entire country to a depth of 30 inches. This is represented by the width of the big arrow to the left side of figure 3. However, not all of the precipitation is available for man's use. Evapotranspiration takes 21 inches. As figure 3 shows, this is water returned to the atmosphere as vapor. This water is not wasted because it supports our vast forests and nonirrigated farms. The remaining 9 inches, which amounts to 1,160 billion gallons per day, is our manageable supply. Three of the nine inches are now being used by man. After use, 2 of the 3 inches reaches the rivers and flows into the oceans; the other inch returns to the atmosphere by evaporation. Those quantities are indicated in figure 3 both by width of arrows and by the figures written on the diagram.

National averages, however, may be misleading because some areas receive much more precipitation than others. As shown on figure 4, the distribution of precipitation in the United States is extremely variable—some areas receive less than 10 inches per year whereas others receive more than 20 inches.

In the country west of the Rocky Mountains annual precipitation varies depending on altitude and exposure. Moisture-laden air from the Pacific Ocean rises as it reaches the mountains, which causes the release of moisture, mostly as snow on the mountains, but some as rain in the valleys. The air is dry as it descends the east side of the mountains; therefore, only a little precipitation is released. This causes rain shadows or dry areas to the lee of all the major ranges and a rather large dry area just east of the Rocky Mountains. Still further east, moisture-laden winds from the Gulf of Mexico become an important source of precipitation. Precipitation over the eastern part of the country varies from 20 to 80 inches in this region. At the present time there is no way of significantly changing the geographic pattern of precipitation over the country.

As precipitation varies with location so does the manageable supply. Runoff is the quantity of water which runs off through surface streams. Although runoff, which is equivalent to the long-term manageable supply, averages 9 inches, it ranges from less than one-quarter inch to about 80 inches. This pattern of runoff, shown in figure 5, is similar to the pattern of precipitation, dry in the lee of the high western mountains and wet along the west coast, on high mountain ranges and in the East. This pattern is controlled mainly by the precipitation and, like precipitation, is practically unchangeable.

The resource is one side of the supply-demand situation; the amount of water used and how we use it is the other side. The use of water in the United States is far from uniform as figure 6 demonstrates. The quantity used, indicated by the size of circles in figure 6, is related to population density and kind of use. For example, more water is used in the moist, heavily populated Ohio River region than in the drier lightly populated Missouri River region, although the Missouri River region is four times as large.

The way the water is used is markedly different in the East than in the West. Note the relative sizes of the slices of pie shown in figure 6. Industry is the predominant use in the East whereas irrigation is the predominant use in the West. This relation is shown for the United States as a whole in figure 7. It shows that 46 percent of all water used is for irrigation, and an equal amount is by industry.

How the water is used has a very pronounced effect on the supply-demand relationship because some uses deplete the supply more than others. The supply is depleted by the amount of water consumed. Consumed water is either evaporated during use or incorporated in the product. Irrigation, one of the most consumptive uses, evaporates about 60 percent of the water used, as shown in figure 7. But, industry, one of the least consumptive uses, evaporates only about 2 percent of the water. Industrial use is largely nonconsumptive because most industrial water is used for cooling. It is a significant fact that 94 percent of all water used by industry is used for cooling. This is shown in figure 8. Cooling water is usually discharged to a stream, unchanged except in temperature. Saline water can be used for cooling, where available, with only minor difficulties, and if it were used instead of fresh

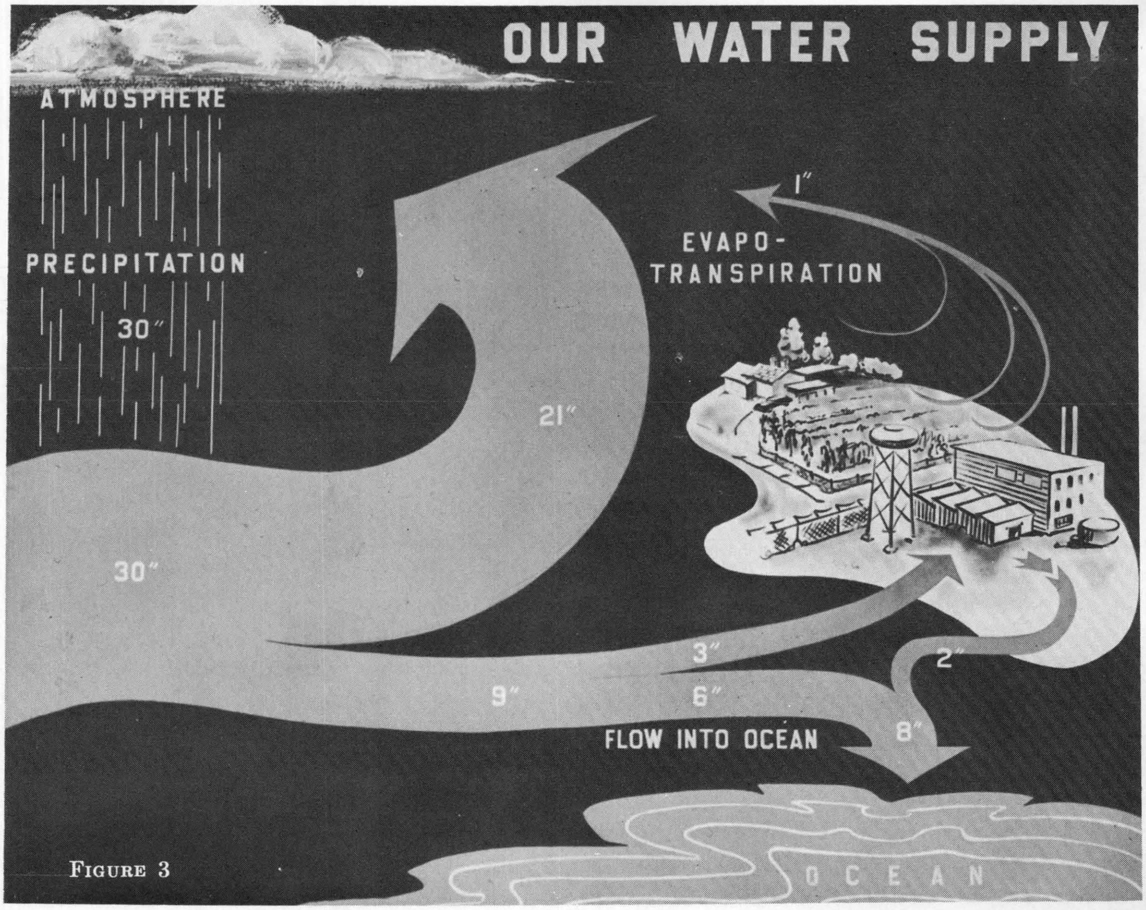

FIGURE 3

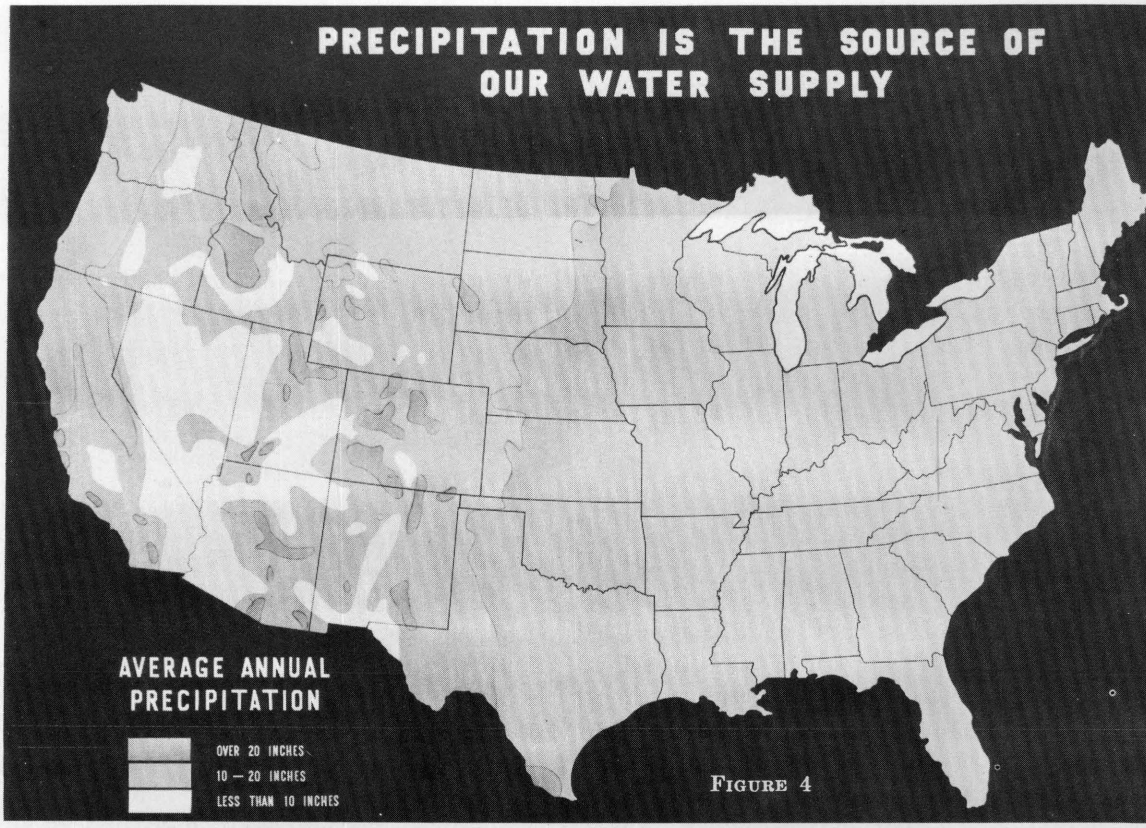

FIGURE 4

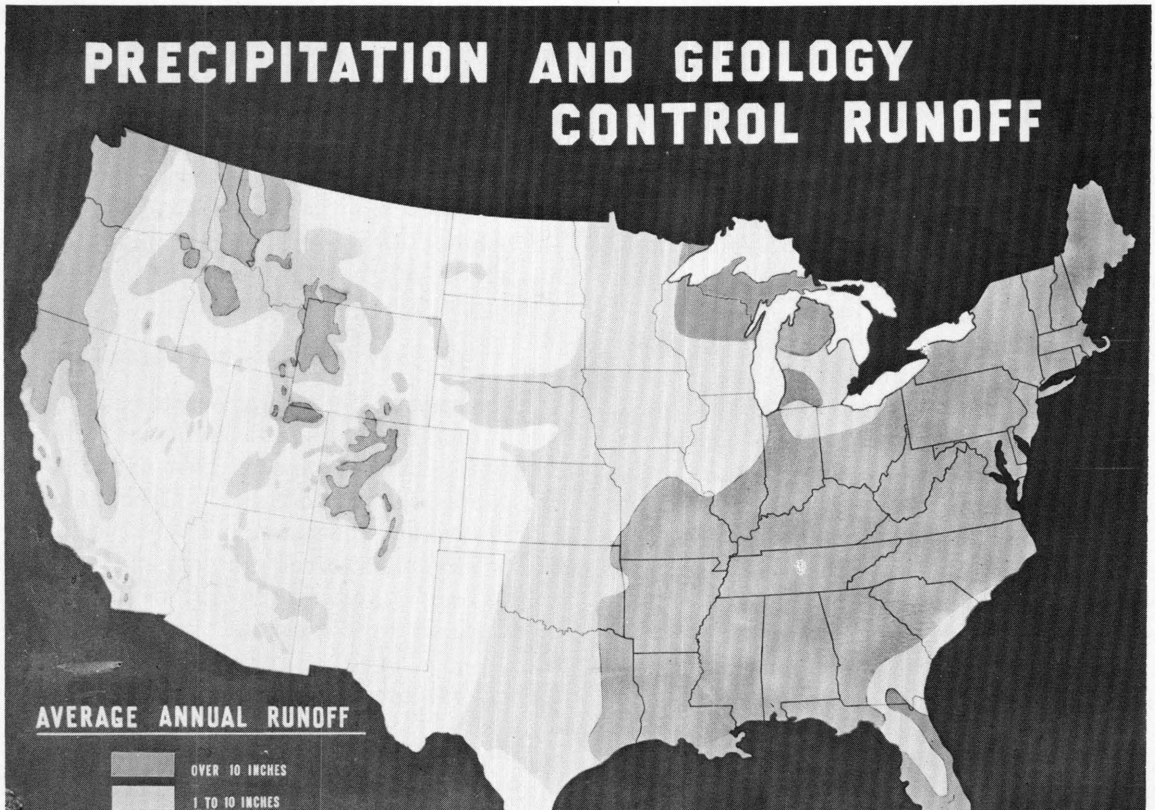

FIGURE 5

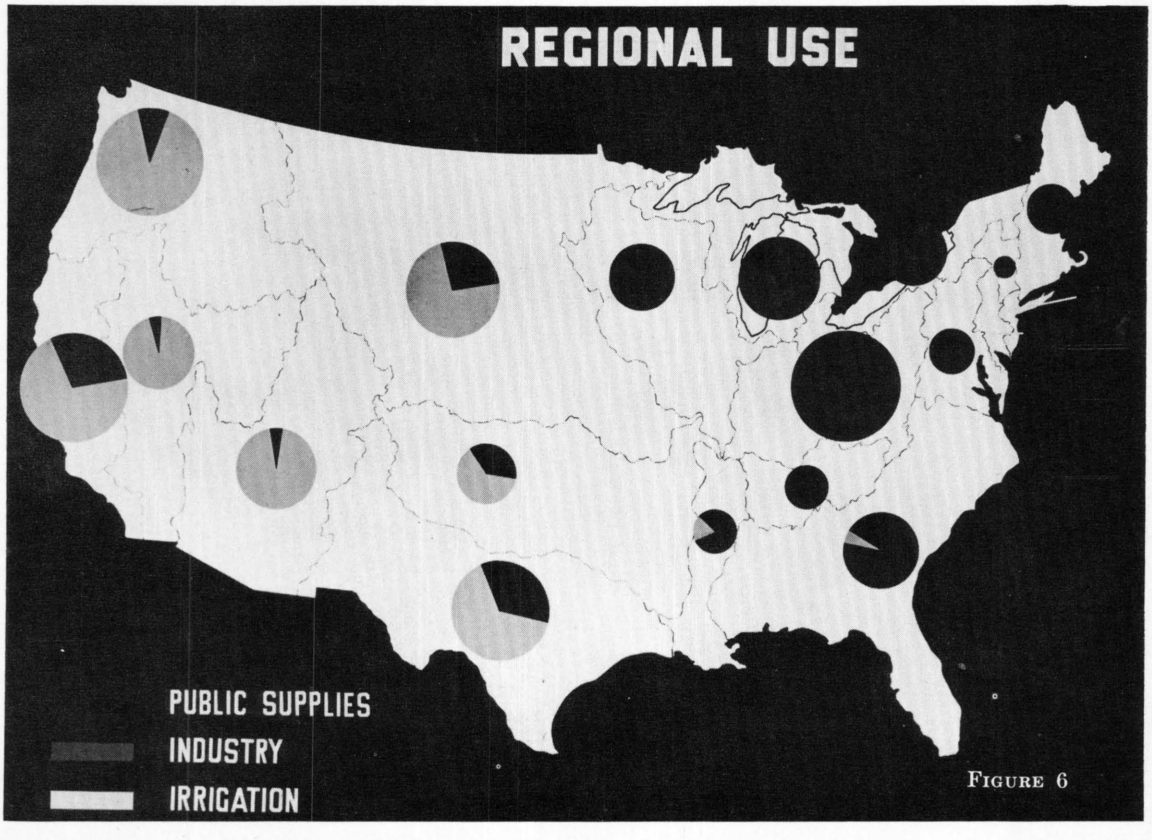

FIGURE 6

water, the latter could be put to uses which saline water would not serve. At present, as shown in figure 8, about one-sixth of all water used by industry is saline.

Most cooling water is used only once and then discarded. The water intake can be greatly reduced by recirculation. On the average the petroleum industry recirculates its water four times. Figure 9 shows that those petroleum plants which extensively recirculate the water draw only 2 barrels of new water out of the supply for every 41 barrels used. This means some water is recirculated about 20 times before it is discarded. Recirculation increases the amount consumed; therefore, if the trend to using cooling water several times continues, a larger percent of the water withdrawn will be consumed. However, the increase in consumptive use will have no important adverse effects on the general supply if withdrawals are from saline sources.

This, then, is the supply-demand situation. The long-term supply is unchangeable and is about equal to the long-term average runoff. Nationwide it is large but it is not uniformly distributed. Although the nonuniform geographic distribution of present withdrawals is an important aspect of the general water problem, the irregular distribution of heavy consumptive uses is even more important. Irrigation greatly depletes the supply in the West where the supply is small, whereas industry depletes the supply but little in the East where the supply is large. The potential demand for water is greater than the resource can supply in the shaded area on the supply map in figure 1.

THE VARIABILITY PROBLEM

Even though the average water supply is adequate to meet average demands, variability is a problem because it means that demands exceed the supply at certain times. Although supply is more variable than demand, the variability of each contributes to the problem.

The supply varies from day to day, month to month, and even year to year. Although the supply may be either greater or less than average for several successive years, no overall increase or decrease can be seen. One often hears the worried question, "Is our water supply decreasing?" There have been, of course, periods of

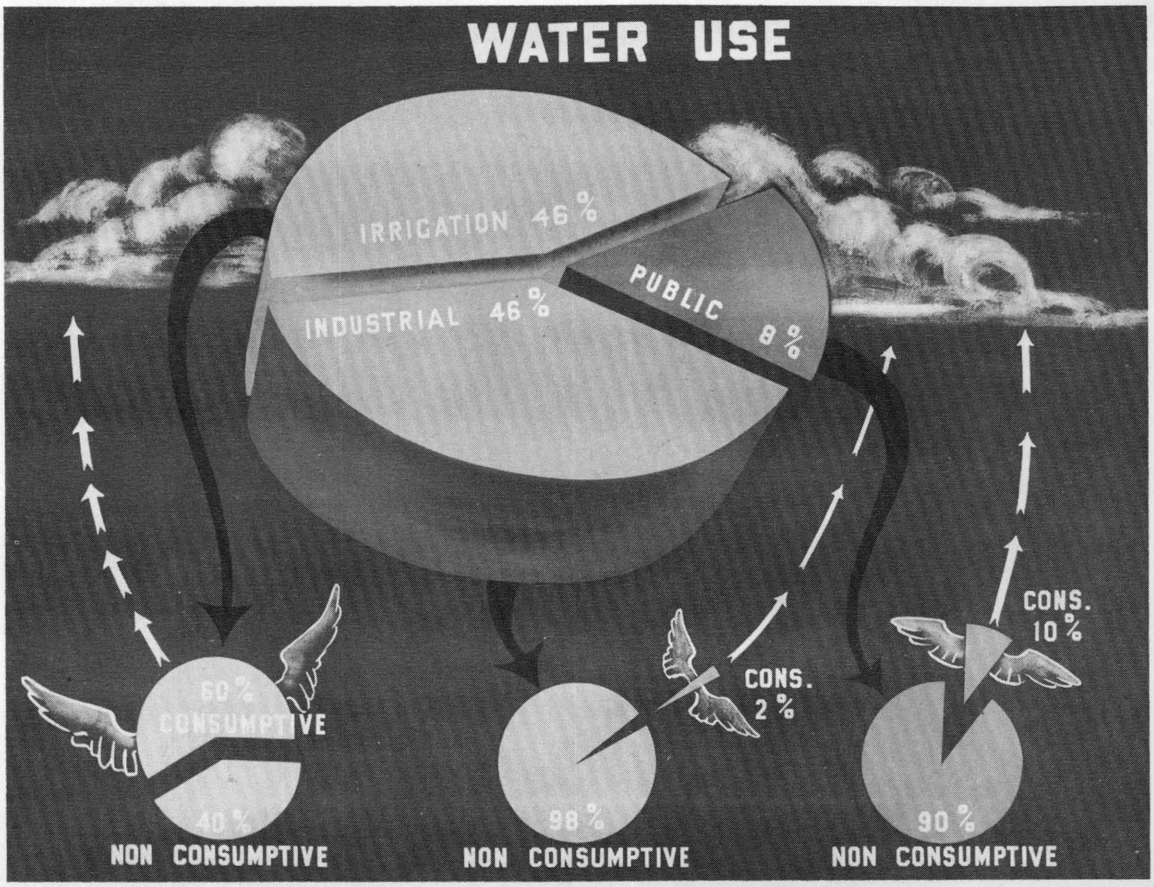

FIGURE 7

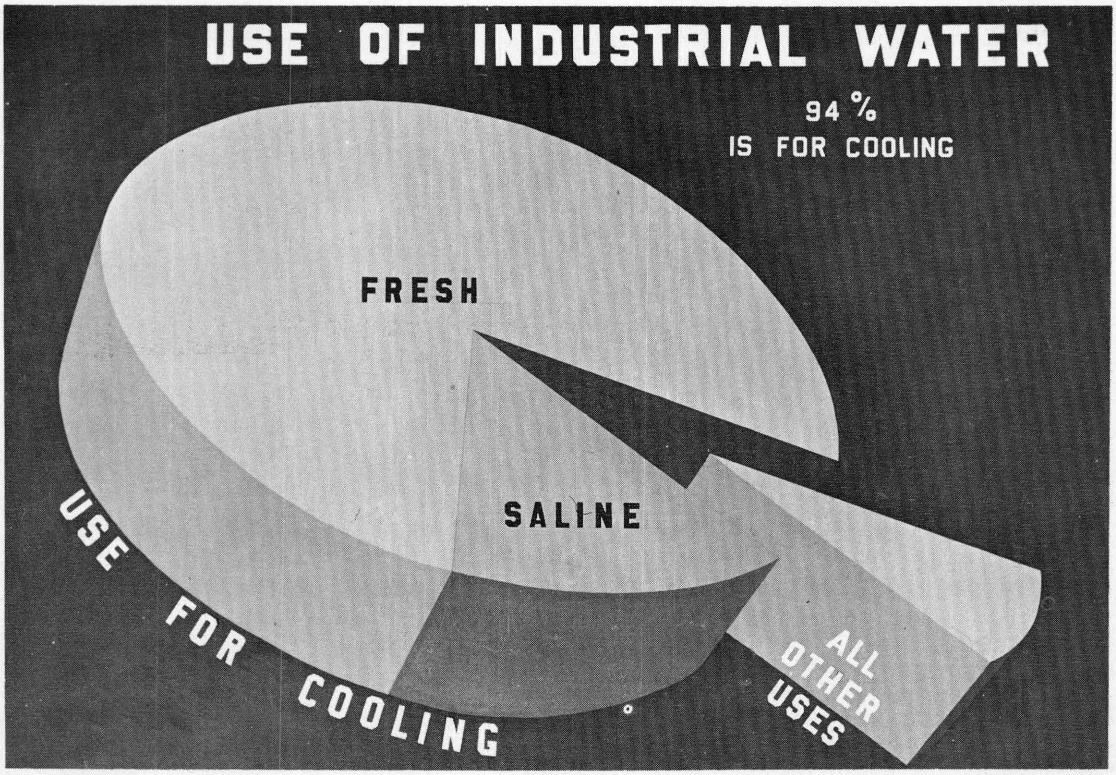

FIGURE 8

intense drought, such as that in the early 1930's, which show up prominently in figure 10. Nevertheless it will be noted that the wetter than average years preceding and following a dry period tend to compensate for the deficiency and the overall average for the country has not appreciably changed in the period of record, 1895 to the present. This balancing of wet and dry periods can be seen in figure 10.

Climate causes much of the variability of supply, but geology is also an important factor. Although the effect of geology is complex, the results of precipitation on various terranes may be demonstrated by analogies. A household sponge is like some of the porous soils and formations of the earth's crust. A large quantity of water can be taken in by a dry sponge. After a specific amount has been absorbed, further additions will run through and drip out the underside of the sponge. The action of water on the sponge is similar to rainfall on the soil mantle. When the soil becomes sufficiently wet some water passes on to the material beneath and contributes to underground storage. Some terranes resemble hard glazed pottery—they do not absorb water. A common cinder building block is analogous to the response of a typical terrane to rainfall. Water applied slowly will be taken up—some of the water applied rapidly will run off the block.

The effect of geology on streamflow is shown by the variation of flow with time plotted in figure 11 for the Loup River in Nebraska and the Bad River in South Dakota. The drainage basins of both rivers receive approximately equal amounts of precipitation; but they yield greatly different hydrographs. The Loup River drains a sandhill area which absorbs most of the precipitation, which adds to ground storage becoming part of the ground-water reservoir. It emerges at an almost uniform rate as streamflow in the Loup River many days later. The Bad River drains a nearly impervious shale area which does not allow the rainfall to infiltrate. The Bad River receives little contribution from ground storage. Thus its flow is not maintained during rainless periods.

One cannot evaluate accurately the variability of supply from hydrographs such as figure 11. However, hydrologists have devised a statistical expression of variability, as shown in figure 12. The flow duration chart expresses variability in graphic form. The *variability index* expresses the same characteristic. A flow duration chart is analogous to a chart showing heights of 1,000 schoolchildren if the number of children taller than selected heights are plotted to cover the full range from shortest to tallest. Instead of showing percent of all children who are taller than specific heights, flow duration charts show the percent of

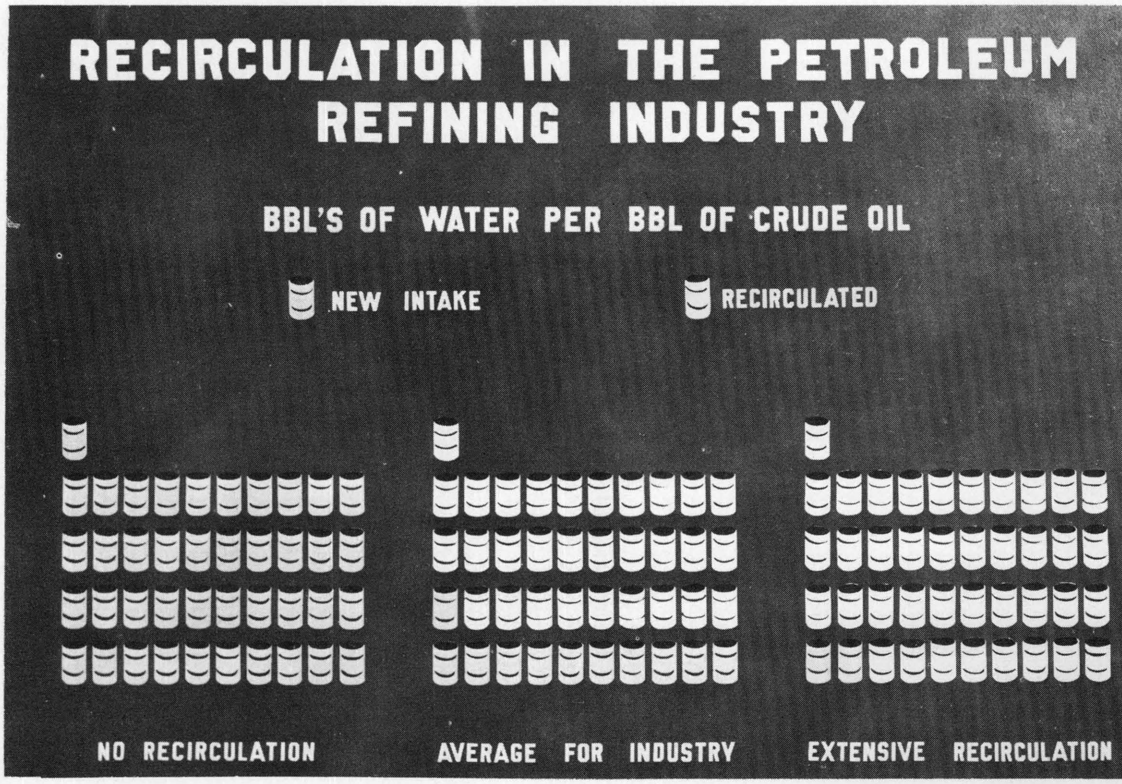

FIGURE 9

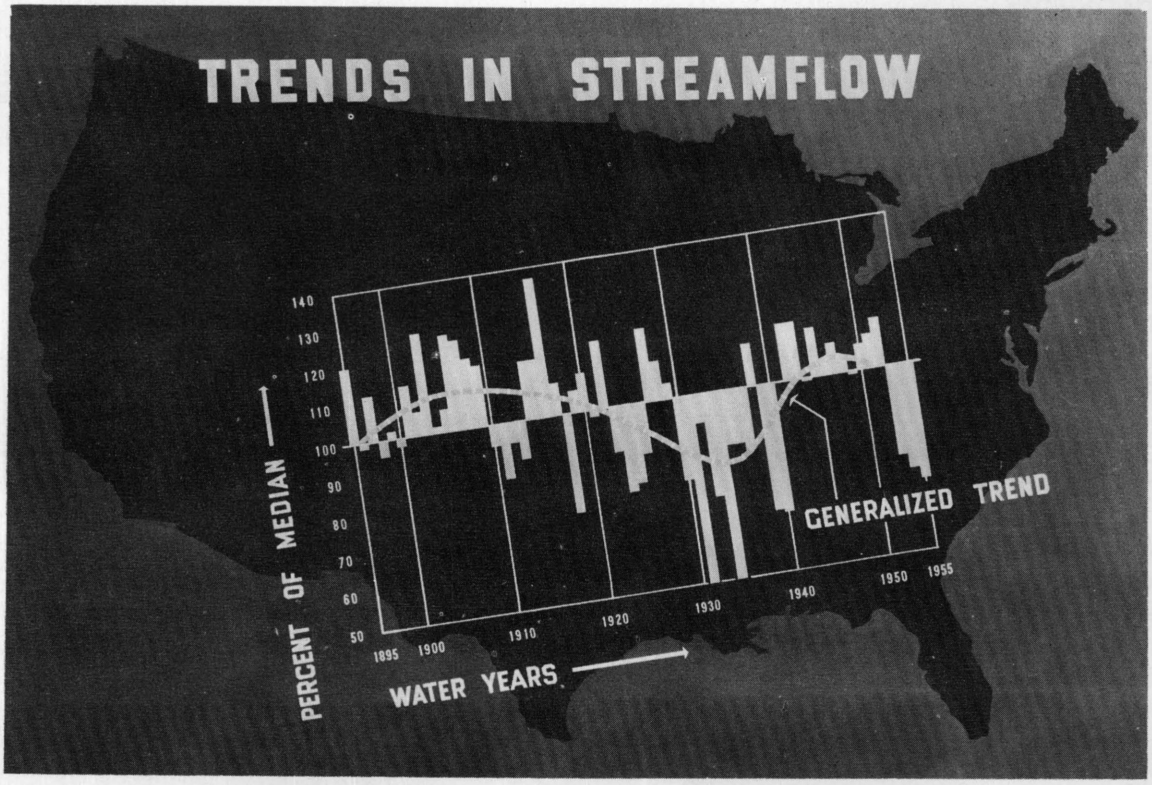

FIGURE 10

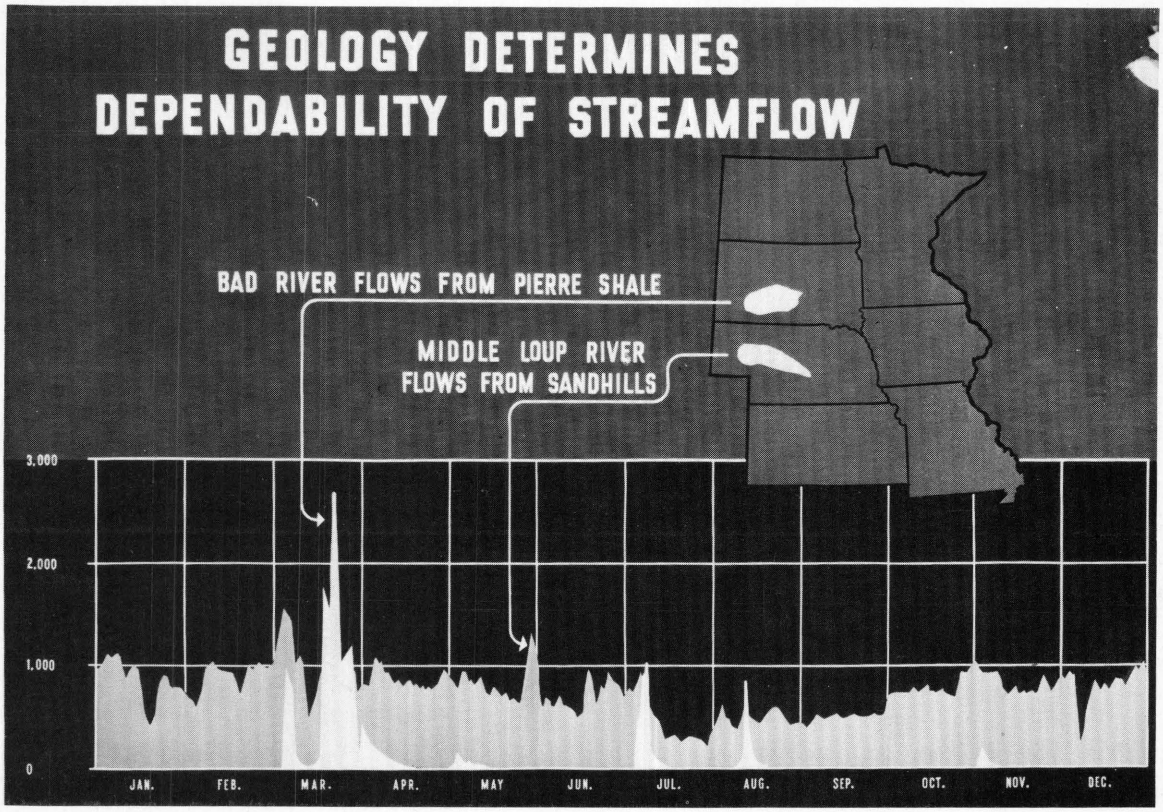

FIGURE 11

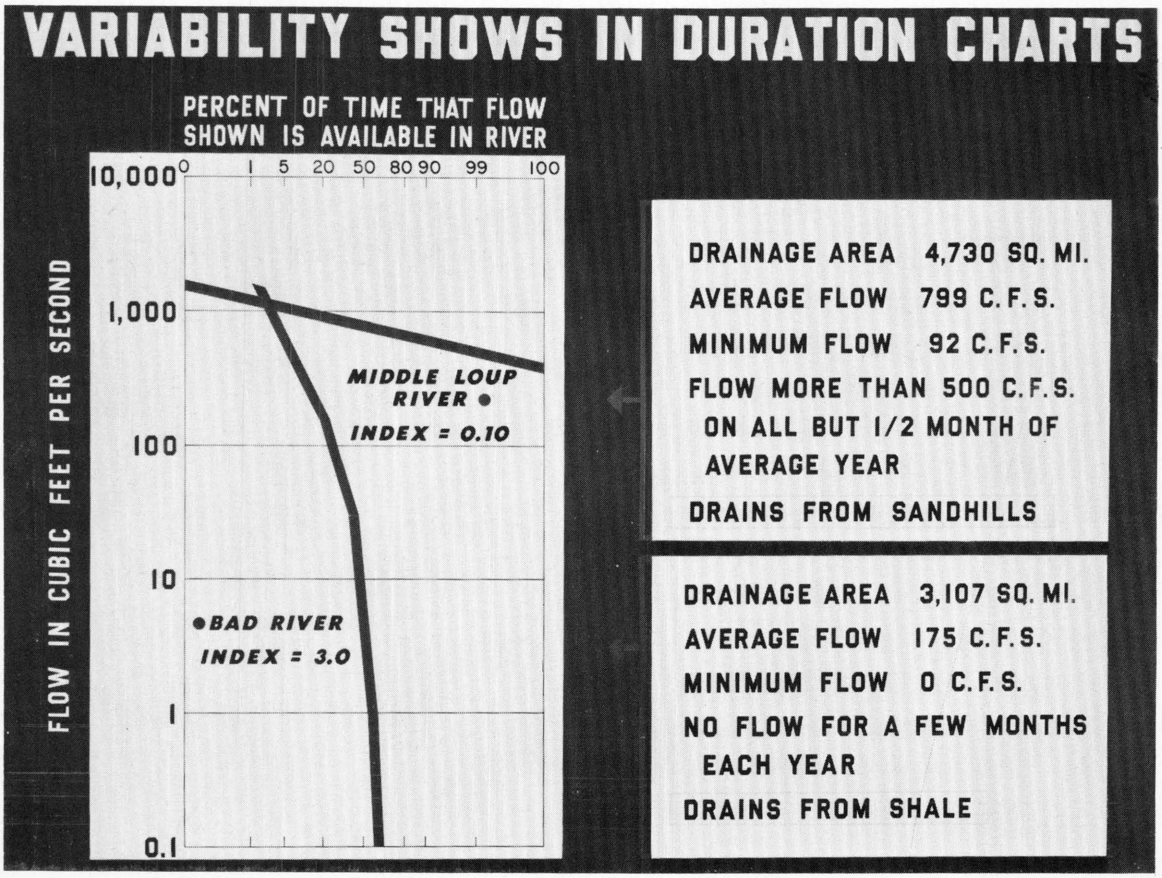

FIGURE 12

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time when flow was equal to or greater than specific discharges. The more variable the streamflow, the more nearly vertical the chart. The *variability index* is the mathematical expression of the slope of the flow duration chart—a high value of the index means great variability—a low index means small variability. Flow duration charts are used in planning water projects to show how storage of water should be provided to furnish supplies during periods of low natural discharge.

The steady flow available naturally in a region is only a fraction of the average annual supply because unregulated streamflow varies. Flow duration charts prepared for total regional streamflow show the percent of time when flow exceeds specific amounts. Duration data computed for 22 regions of the United States (see fig. 12A) are presented in table 1. Note that, for New England, the average supply is 65,000 million gallons per day but only 6,300 million gallons per day are available 95 percent of the time. This means that without storage one can rely on a supply of at least 6,300 million gallons per day for all but 18 days of a typical year. Quantities shown in table 1 represent present use and supply available for further use.

Water demands are the other side of the variability problem. Demands for public supply are almost constant; irrigation demands highly seasonal. Most irrigation water is used during the 3- or 4-month growing season and practically none during the remainder of the year. As shown in figure 6, this highly seasonal use predominates in the West where the supply is small and variable. Variability is a problem in the shaded area on the lower right-hand map in figure 1. Variability is not always undesirable because sometimes the season of greatest supply coincides with the season of greatest demand. Snowmelt in some western rivers, for example, Columbia River on figure 13, coincides with demand for irrigation water.

The demands for industrial water are less variable than demands for irrigation water; however, there is some variation from month to month and place to place. The demand for cooling water is somewhat seasonal, especially if refrigeration or air conditioning is important in the industry. Some industries such as food processing have highly seasonal water demands.

Unlike the supply problem we have a ready but not easy solution for the variability problem—storage. Water may be stored either under ground or above ground in times of plentiful supply and withdrawn in times of need. Stored water may be compared to savings in a bank as portrayed in figure 14. During periods of plentiful natural supply the water in the "bank," or underground aquifer, can be replenished for future use when withdrawals must come from the

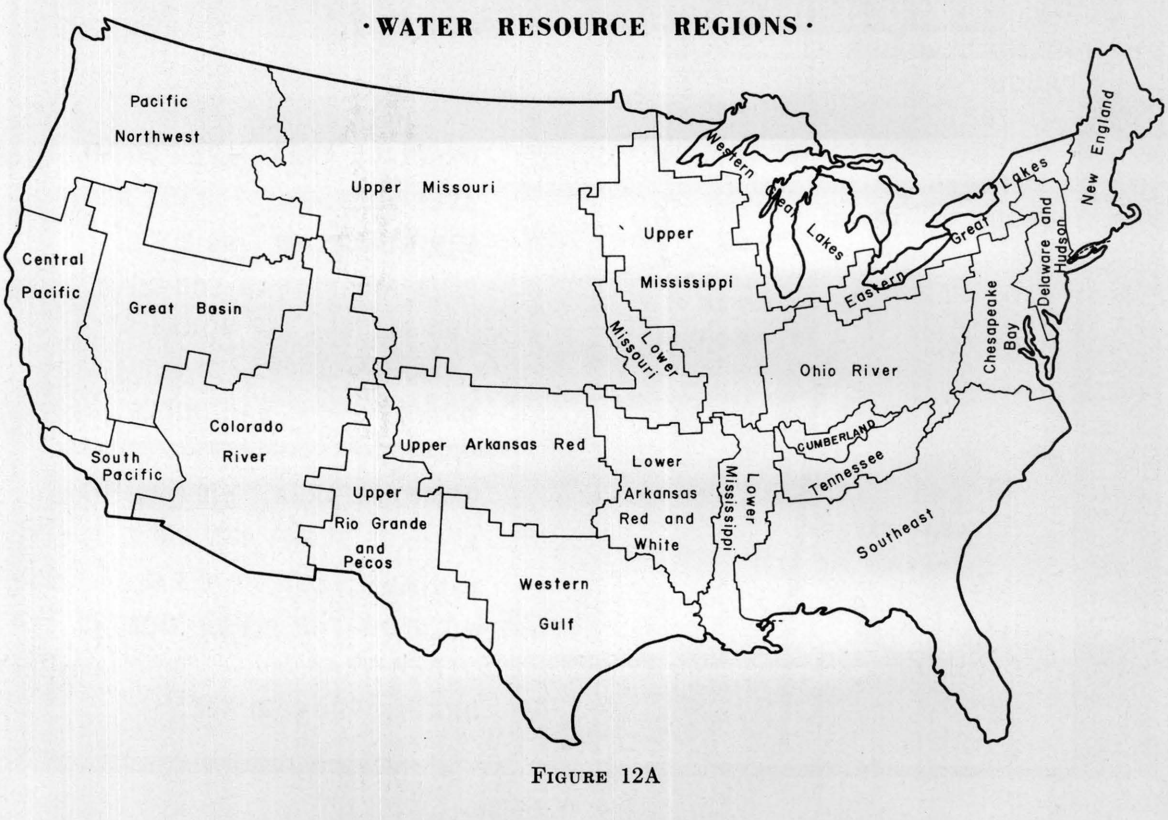

FIGURE 12A


NATURE FREQUENTLY FURNISHES WATER WHEN NEEDED
COLUMBIA RIVER
YELLOWSTONE RIVER
RED RIVER
REPUBLICAN RIVER
ROARING FORK
VERDE RIVER
GUADALUPE RIVER
BUFFALO RIVER
PECATONICA RIVER
SUSQUEHANNA RIVER
SOUTH FORK HOLSTON RIVER
CHATTAHOOCHEE RIVER
KISSIMMEE RIVER
J F M A M J J A S O N D

FIGURE 13

TABLE 1.—*Present use and supply available*

Region	Area (thousand square miles)	Present use (million gallons per day)	Average supply remaining (million gallons per day)	Streamflow available for indicated time (million gallons per day)				
				95	90	80	70	50
New England	59	5,900	67,000	6,300	9,700	16,000	22,000	39,000
Delaware and Hudson Rivers	31	15,000	32,000	3,200	4,800	7,800	11,000	19,000
Chesapeake Bay	57	4,700	52,000	5,600	8,400	13,000	18,000	32,000
Southeast	279	12,000	212,000	21,000	31,000	49,000	71,000	126,000
Western Great Lakes	81	15,000	42,000	8,400	12,000	16,000	21,000	32,000
Eastern Great Lakes	47	11,000	40,000	2,300	3,700	6,500	9,700	19,000
Ohio River	145	24,000	110,000	7,400	9,400	15,000	21,000	46,000
Cumberland River	18	5,000 (Cumberland and Tennessee combined)	17,000	1,500	2,100	3,300	4,500	7,800
Tennessee River	41		43,000	9,000	11,000	15,000	19,000	28,000
Upper Mississippi River	182	9,200	62,000	7,800	12,000	18,000	25,000	41,000
Upper Missouri River	518	23,000 (Upper and Lower Missouri combined)	19,000	1,200	1,800	3,200	4,500	9,000
Lower Missouri River	62		23,000	410	550	1,200	2,200	5,800
Upper Arkansas-Red Rivers	153	7,600 (Upper Arkansas-Red and Lower Arkansas Red and White combined)	11,000	410	700	1,300	2,100	4,500
Lower Arkansas Red and White Rivers	117		77,000	1,000	2,100	4,400	8,400	20,000
Lower Mississippi River	64	5,100	49,000	2,100	3,600	6,500	10,000	21,000
Upper Rio Grande and Pecos River	136	20,000 (Upper Rio Grande and Western Gulf combined)	[1]	[1]	[1]	[1]	[1]	[1]
Western Gulf	205		46,000	920	1,700	3,400	5,900	14,000
Colorado River	258	17,000	3,200	210	320	560	830	1,700
Great Basin	200	12,000	3,700	300	470	780	1,200	2,100
South Pacific	13	27,000	360	30	40	60	100	180
Central Pacific	99	28,000	47,000	1,000	1,900	3,800	6,300	16,000
Pacific Northwest	257	----------	143,000	9,700	21,000	26,000	39,000	76,000
United States	3,000	240,000	1,100,000	90,000	140,000	210,000	300,000	560,000

[1] Appropriations currently exceed supply.

"bank." Fortunately, nature automatically captures some of the water income and stores it in the water bank. The effect of storing water in porous ground is shown by the Loup River hydrograph in figure 11, and the effect of storing water on the mountain as snow is shown by the distribution of flow in the Columbia River in figure 13. Natural storage, although abundant and cheap, is not as effective as manmade storage because it depends on natural forces to store and release the water.

Man can assist nature by withdrawing water stored in the ground through wells. Ground water has been a mysterious subject from ancient times; however, in recent decades scientific knowledge has begun to supplant superstition. Although some rock formations do not have the ability to yield large quantities of water to wells, small supplies sufficient for domestic and stock use can be obtained almost everywhere. The water-yielding ability of rock formations in large geographical areas is shown in a general way in figure 15 and table 2.

A dry formation cannot yield water to wells although it may be able to transmit water freely; therefore, rainfall must be adequate to replenish the ground-water body when water is withdrawn through wells or discharges naturally through springs and seeps.

The wide range in availability of ground water is illustrated by conditions in the Atlantic Coastal Plain, the Southern Appalachian Highlands, and the Southern Great Plains (areas A, C, B in fig. 15). The extensive beds of sand, gravel, and limestone underlying the Atlantic Coastal Plain yield large quantities of water. Precipitation, which averages more than 45 inches per year, is ample to replenish the supply. On the other hand, in the Southern Appalachian Highlands, where rainfall is also 45 inches, the rocks will not yield water to wells in large quantities.

The situation in the Southern Great Plains is very different. The rocks underlying the area yield large quantities of water to wells and at present the formation contains large quantities of water. However, only about 0.2 of an inch of the 20-inch annual precipitation reaches the ground-water body. Most of the precipitation is used by growing plants or is evaporated from the soil or ponds.

The water situation in the Southern High Plains portion of the Southern Great Plains is shown in figure 16. Since 1935, when annual withdrawals about equaled the annual recharge rate of 50,000 acre-feet, pumping rates have steadily increased until in 1958 the withdrawal was 7 million acre-feet. The reserve of about 200 million acre-feet will be exhausted in about 30 years if the present rate of pumping is continued. Removing ground water faster than it is being replenished is called mining. Mining causes water levels to fall which increases the cost of obtaining the water. If mining is continued the water table will fall so low and the water will become so expensive that some users will not pump it.

Water mining may develop when water users are not aware of the hydrologic conditions that

FIGURE 14

TABLE 2.—*Availability of ground water*

Areas	Water use (excluding water power)—use in millions of gallons per day and percent of total from ground water sources		Availability of ground water
	Total (million gallons per day)	Ground water (percent of total)	
A. Atlantic and Gulf Coastal Plain area	32,000	25	Abundant water supplies in sand and limestone. Large potential. Salt-water encroachment a factor near coast.
B. Southern Great Plains area	21,000	45	Abundant supplies in sand and gravel, but replenishment low, especially in southern part—large demands result in mining of of the water.
C. Appalachian Mountain and Piedmont area	8.000	50	Small but reliable supplies for domestic and limited municipal and industrial use. Potential good for limited demands.
D. Rocky Mountains, northern Great Plains, and northern Pacific Coast area.	28,000	12	Generally small supplies adequate only for domestic and stock use. Quality very poor in places. Potential not great.
E. Unglaciated central plateaus and lowlands	26,000	10	Bedrock generally yields meager supplies, often of poor quality. Large supplies of hard water from limestone locally. Valley alluvium yields moderate and locally large supplies of variable quality. Potential not great.
F-1. Basin and range	41,000	42	Productive valley alluvium, but recharge low in many places. Large developments may "mine" the water. Substantial potential with judicious management.
F-2. Columbia Plateau	24,000	7	Productive lava rocks throughout province. Locally, recharge is generous. Potential still great with proper management, especially in eastern part (Snake River Plain), which contains one of largest unused ground-water supplies in the Nation.
G. Glaciated area of the East and Midwest	57,000	10	Glaciated area, many local deposits of productive and amply recharged sand and gravel. Bedrock variable but highly productive in relatively few places. Substantial potential for future.
U.S. total (rounded)	240,000	20	

control recharge to the pumped aquifer. Water mining may also be deliberate if the profits warrant exploitation of the water resource. Locally the conditions may be simple or complex. Ground water beneath a particular location may be rainfall which percolated to the local aquifer only a short time ago or it may be rainfall which percolated into the local aquifer many miles away and many years ago. At some locations water may be withdrawn from aquifers under water table conditions or, by a deeper well, from an aquifer under artesian conditions as will be explained.

Ground water under artesian conditions is analogous to water under pressure in a city water main. The water in the beds shown in the lower right-hand portion of figure 17 is artesian water—it is under pressure and would rise, under conditions of no pumping, to just beneath the pump. When water is withdrawn from a city water main the result is a reduction of pressure all along the main—yet the main continues to run full if the water supplied to the main was under sufficient pressure. Likewise, the artesian water in figure 17 will have a great reduction in pressure when the well is pumped. Ground water under water table conditions is analogous to water in a tub of sand—if a withdrawal of water is made at one point the water surface will drop in the sand—the water surface forms a cone of depression surrounding the point of withdrawal, as is shown for the two water table wells in the left portion of figure 17.

Sometimes man can assist nature in recharging the ground-water reservoir if the geology is suitable. The rocks must be able to absorb the water and to yield it to wells. Furthermore, a supply of surplus water must be available. Recharge is now practiced successfully in several places. Long Island and California are examples.

Cooling water for many air-conditioning systems on Long Island is obtained from wells. The used cooling water is discharged into other wells thus recharging the aquifer. Low barriers have been built across the debris cone at the mouth of some canyons in California. When the floodwaters rush from these canyons the barrier holds the water for a few days until it seeps into the very porous debris cone, thus replenishing the aquifer.

Artificial recharge is not the remedy for water

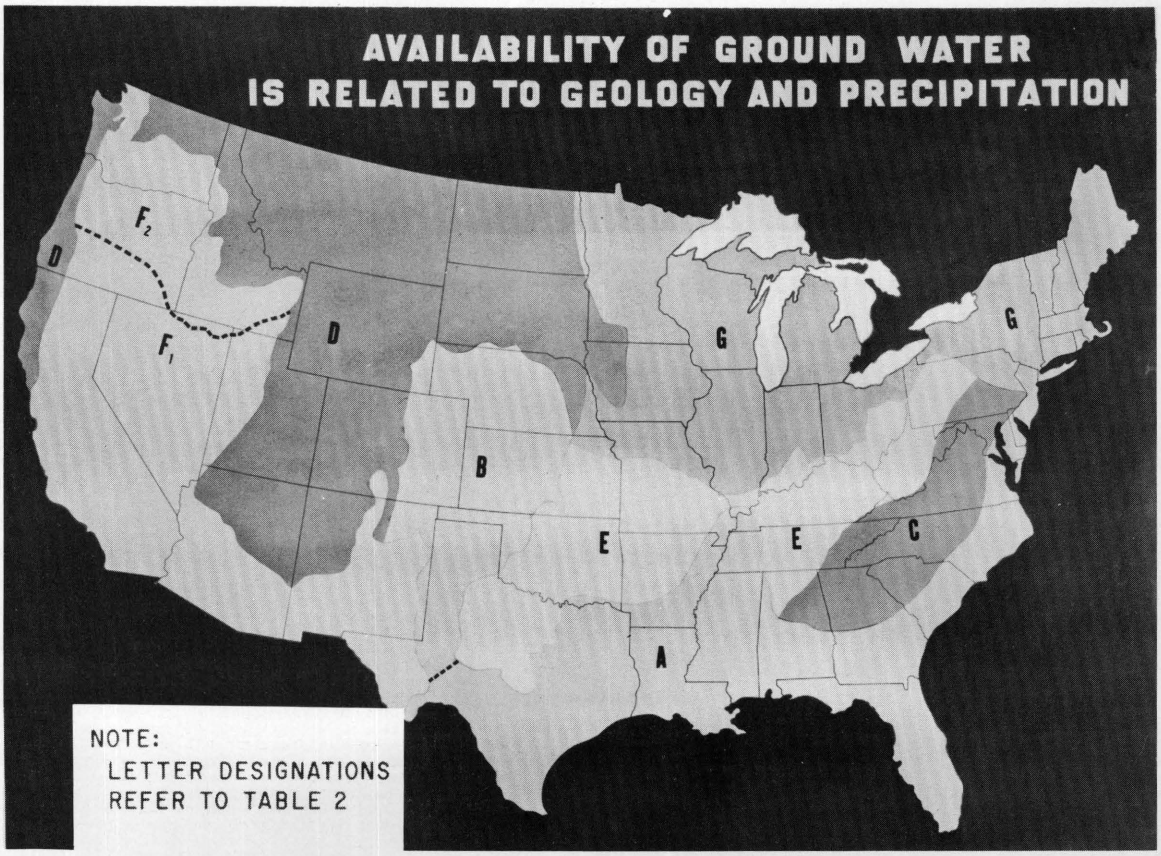

Figure 15

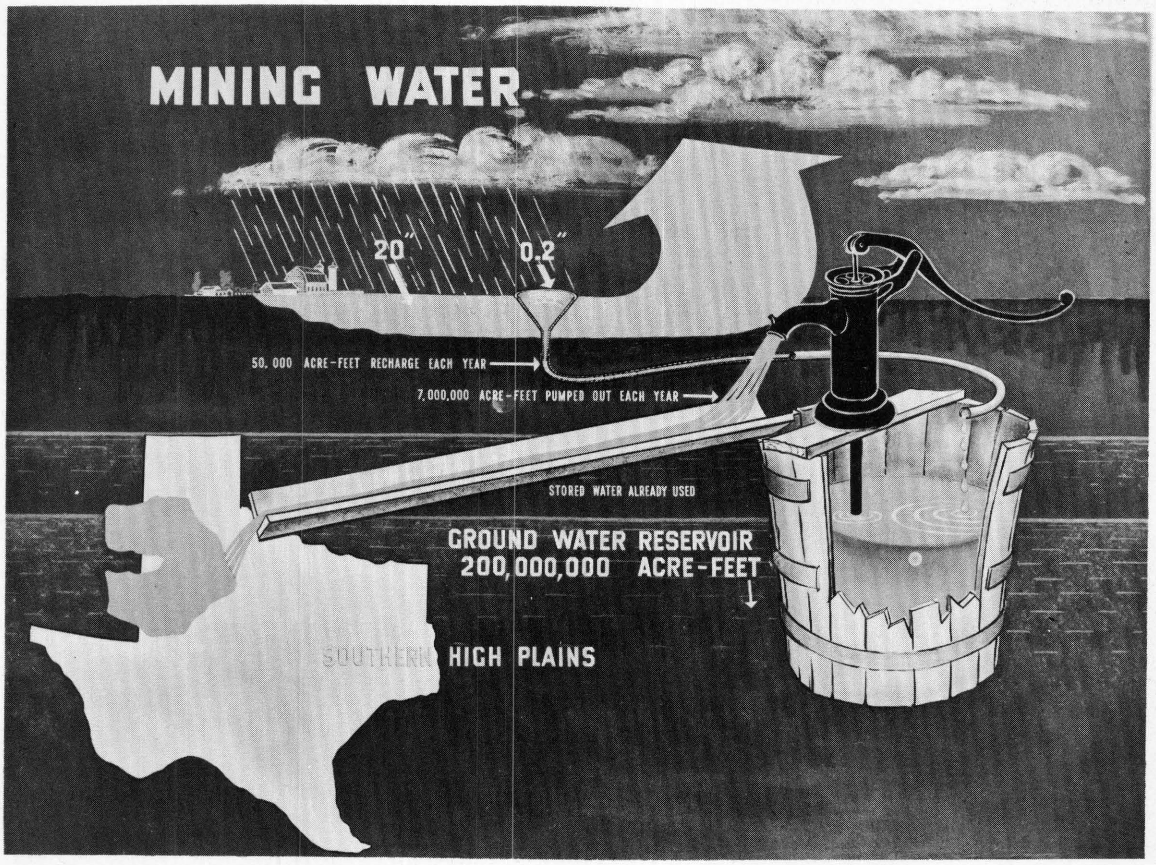

FIGURE 16

mining everywhere. For example, surplus water is not available to recharge the ground-water reservoir of the southern High Plains area.

Large wells constructed in river valleys are pumped at many places in the United States. Because the material underlying the top soil in the valley is normally a coarse sand or gravel, it transmits water readily. When the wells are pumped for many days river water moves through the valley deposits to the wells, as shown in figure 18. Eventually the pumped wells have the same effect on the stream as diversion directly from it. In some places pumping ground water may rob holders of surface-water rights. The State engineer of New Mexico has ruled that additional wells cannot be drilled along the Rio Grande unless the right to surface water is acquired. Depletion of streams by pumping from valley alluvium is a problem is parts of California, Arizona, New Mexico, Colorado, Kansas, and Nebraska.

Although tremendous quantities of water may be stored in the ground, artificial recharge is not common. Surface storage is common, probably because it can be seen and easily understood. Storage in surface reservoirs increases the availability of supply—flow larger than unregulated flow is made available when needed. By storage, a specific flow can be made dependable for a specific period. The dependable flow that can be obtained by storage at a particular place has theoretical and practical limitations. Theoretically the dependable flow cannot be greater than the long-term average; however, practically a dependable flow of that size cannot be obtained.

Increasing storage cost is one reason that a dependable flow approaching the average is impractical. Figure 19 illustrates the diminishing return from reservoirs on a small stream in central Indiana. The stream has a dependable flow of 9 million gallons per day without storage. By providing 8,800 million gallons of storage, the dependable flow would be increased to 35 million gallons per day. In order to double the dependable flow (to 70 million gallons per day) more than four times as much storage would be required.

Evaporation loss is the other reason that it is impractical, if not impossible, to obtain a dependable yield approaching the long-term average flow. In the West evaporation rates from reservoir surfaces are high, as shown in figure 20, and limit the

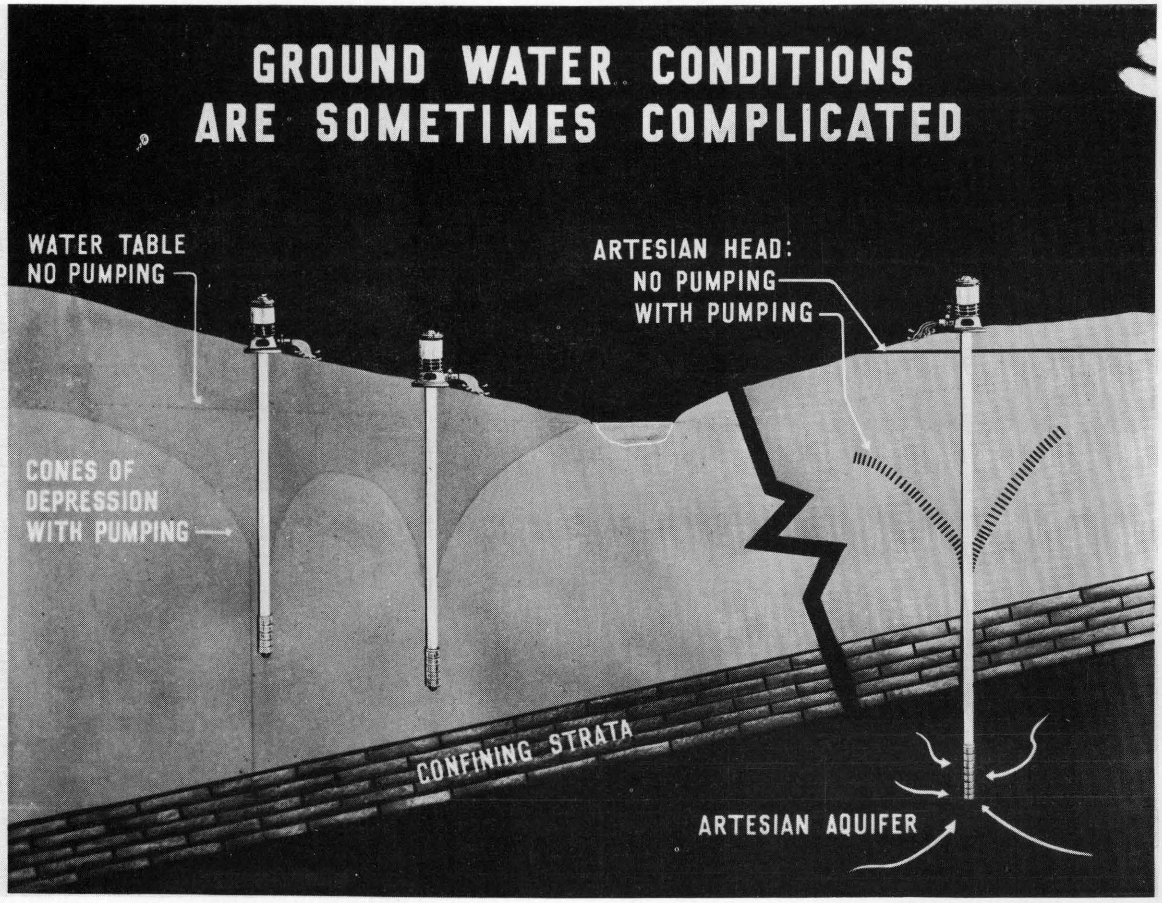

FIGURE 17

gains in dependable supply via reservoirs. At Lake Mead, for example, evaporation skims off the top 7 feet of water each year. Greater dependable supplies require greater reservoirs having larger surfaces. The larger surfaces permit more evaporation. Beyond a specific size of reservoir evaporation losses offset expected increases in dependable flows.

Though storage in surface reservoirs has limitations it will continue to be much used for making larger flows dependable at time of need. For many water uses, such as municipal and industrial supplies, the flows must be available every day. For irrigation supplies flows need to be dependable only during the growing season. Regional storage requirements are presented in table 3. The storage listed in the table will make the associated flow available all the time; e.g., 1,300,000 acre-feet of storage in the New England region makes a flow of 6,300 million gallons per day available 100 percent of the time. As a matter of interest, the regional flows listed in table 3 are the same as the regional natural flows (no storage) for 95, 90, 80, 70, and 50 percent of the time. In some regions, total usable capacity of existing reservoirs may exceed the storage required to make the 50 percent of time natural flow available every day.

THE DISTRIBUTION PROBLEM

Distribution becomes a problem when demands exceed supply in one part of a region, although there may be a surplus in other parts of the region or adjacent regions. This condition occurs when the supply and demand do not coincide geographically.

The distribution problem can be solved by construction of canals and aqueducts. New York, Los Angeles, and San Francisco water supplies are examples. New York reaches 125 miles to the Schoharie Creek and 110 miles to the Delaware River basin for water, San Francisco goes 150 miles to the Tuolumne River, and Los Angeles goes about 250 miles to the Colorado River. Although water can be transmitted through canals and aqueducts, sometimes at a considerable additional cost, evaporation and seepage losses from canals may be appreciable. Because of the distribution of runoff in the United States, the West has fewer major streams than the East, as shown in figure 21. The low density of major streams

Table 3.—*Storage required to produce selected dependable flows*

Region	Storage required to produce indicated flow 100 percent of time									
	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)	Flow (million gallons per day)	Storage (thousand acre-feet)
New England	6, 300	1, 300	9, 700	1, 900	16, 000	4, 200	22, 000	7, 300	39, 000	26, 000
Delaware and Hudson Rivers	3, 200	590	4, 800	900	7, 800	2, 000	11, 000	3, 800	19, 000	11, 000
Chesapeake Bay	5, 600	960	8, 400	1, 400	13, 000	3, 400	18, 000	6, 000	32, 000	20, 000
Southeast	21, 000	4, 900	31, 000	7, 800	49, 000	14, 000	71, 000	25, 000	126, 000	78, 000
Western Great Lakes	8, 400	780	12, 000	1, 100	16, 000	2, 800	21, 000	5, 100	32, 000	20, 000
Eastern Great Lakes	2, 300	720	3, 700	1, 100	6, 500	2, 200	9, 700	3, 700	19, 000	11, 000
Ohio River	7, 400	4, 100	9, 400	5, 200	15, 000	7, 200	21, 000	11, 000	46, 000	29, 000
Cumberland River	1, 500	160	2, 100	290	3, 300	620	4, 500	1, 100	7, 800	3, 100
Tennessee River	9, 000	400	11, 000	600	15, 000	1, 200	19, 000	2, 500	28, 000	9, 600
Upper Mississippi River	7, 800	1, 100	12, 000	2, 300	18, 000	5, 200	25, 000	8, 700	41, 000	26, 000
Upper Missouri River	1, 200	340	1, 800	660	3, 200	1, 200	4, 500	2, 100	9, 000	5, 700
Lower Missouri River	410	660	550	840	1, 200	1, 300	2, 200	2, 300	5, 800	5, 200
Upper Arkansas-Red Rivers	410	250	700	410	1, 300	720	2, 100	1, 200	4, 500	3, 000
Lower Arkansas-Red and White Rivers	1, 000	1, 400	2, 100	2, 500	4, 400	5, 000	8, 400	9, 400	20, 000	22, 000
Lower Mississippi River	2, 100	900	3, 600	1, 800	6, 500	3, 200	10, 000	5, 500	21, 000	14, 000
Upper Rio Grande and Pecos Rivers	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Western Gulf	920	1, 300	1, 700	1, 700	3, 400	3, 800	5, 900	5, 500	14, 000	12, 000
Colorado	210	90	320	120	560	230	830	380	1, 700	1, 200
Great Basin	300	72	470	100	780	240	1, 200	420	2, 100	1, 000
South Pacific	30	10	40	13	60	26	100	43	180	119
Central Pacific	1, 000	880	1, 900	1, 760	3, 800	3, 100	6, 300	5, 300	16, 000	11, 400
Pacific Northwest	9, 700	2, 600	21, 000	6, 600	26, 000	9, 300	39, 000	16, 000	76, 000	47, 000
United States	90, 000	24, 000	140, 000	40, 000	210, 000	71, 000	300, 000	120, 000	560, 000	350, 000

[1] Appropriations currently exceed supply.

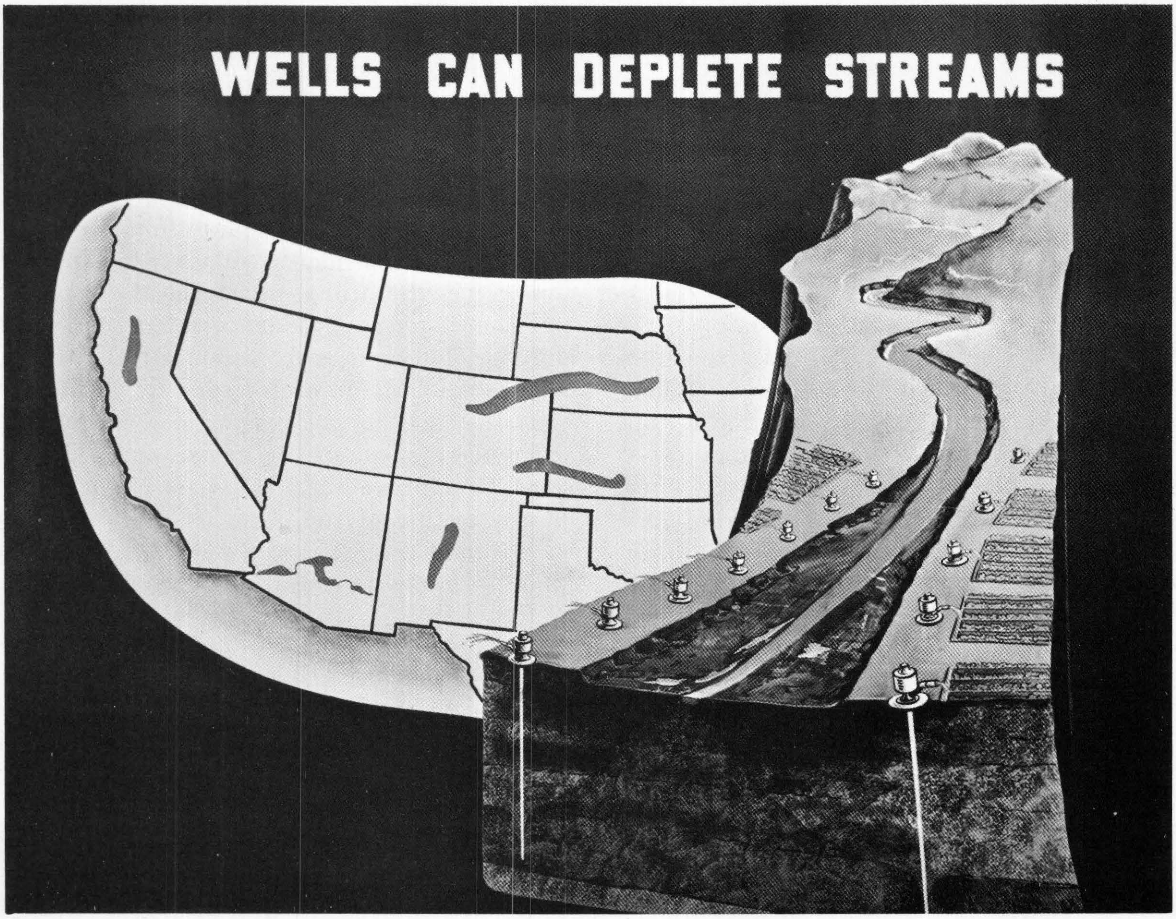

Figure 18

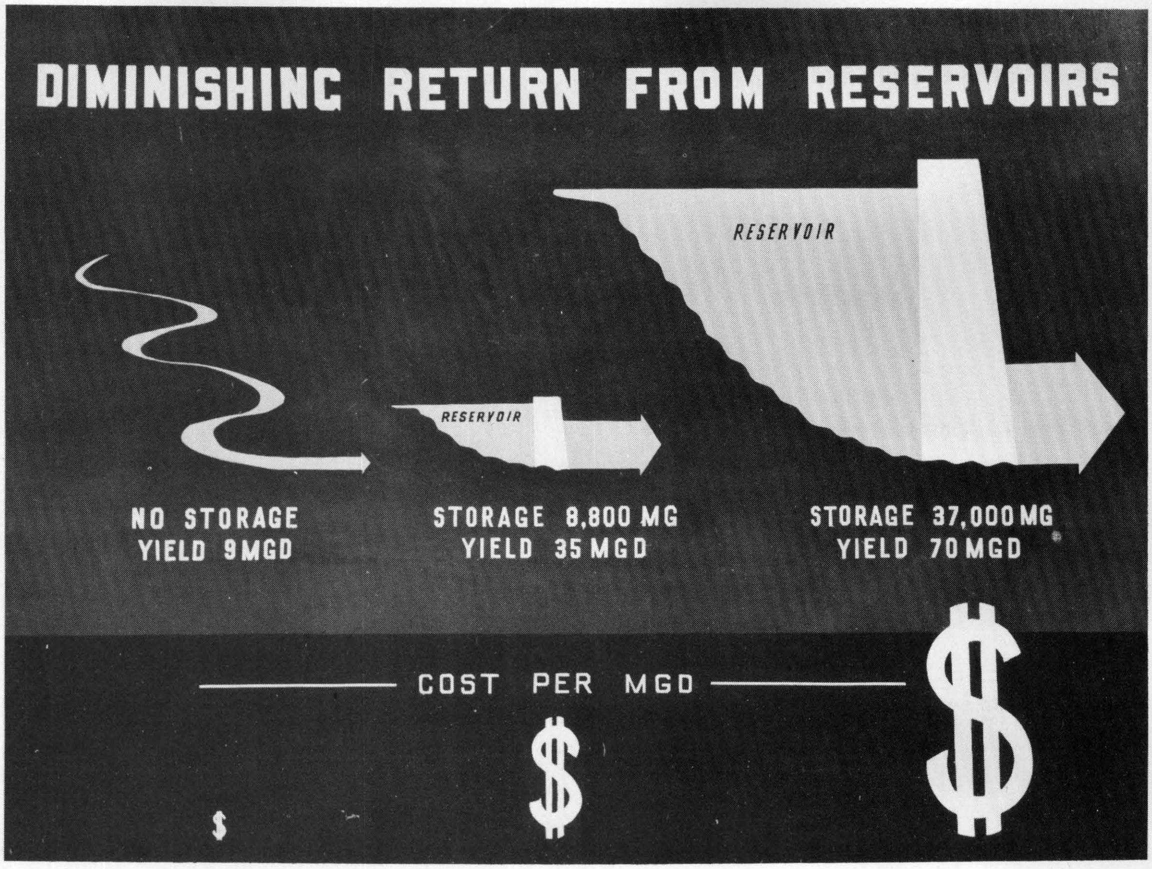

FIGURE 19

in the West raises the cost of distribution for canals and pipelines.

CHEMICAL AND SEDIMENT PROBLEMS

Of all future water problems, those associated with quality promise to be the most troublesome. Even now, people have difficulty in differentiating between naturally bad water and bad water resulting from man's actions. Natural supplies are extremely variable in quality. In great parts of the Nation the water has always been of poor quality. Furthermore, our way of life is continually changing, therefore water quality is viewed differently today than it was yesterday. Yesterday the average man had little recreation—today outdoor life seems within reach of all. Fishing, boating, and swimming have made the public quite conscious of water quality..

Overzealous campaigns to "clean up the streams" are likely to result in confusion about the reasons for poor water quality. Figure 22 and 23 show how natural quality problems can be confused easily with manmade problems. It will do no more good to pass a law prohibiting seasonal variation in the chemical composition of a river, or the ocean's flow into an estuary, than it would to outlaw droughts. However, man's actions such as disposing of industrial and radioactive wastes, can be controlled; and other problems like reservoir sedimentation can be minimized by adequate planning and design of facilities.

Water quality—the amount of matter dissolved (solutes) or suspended (sediment) in pure H_2O—determines the utility, or worth, of a water for a particular purpose. Some waters are suitable only for fighting fires or washing streets; they have low value. Others are of such excellent quality that they are in great demand. Therefore, the effect of water quality on its use, and what can be done to improve the quality, is important. An understanding of the origin of solutes and sediments and the reasons why water quality differs in time and space is necessary for proper management of supplies.

Most solutes of natural origin come from weathering of soil and rocks and from biological reactions in the soil and water. A small amount of salt is brought down by precipitation, and occasionally some comes from mixing of fresh water with ancient brines left in the ground by retreating seas. Weathering is generally a slow process although some rocks break down rapidly.

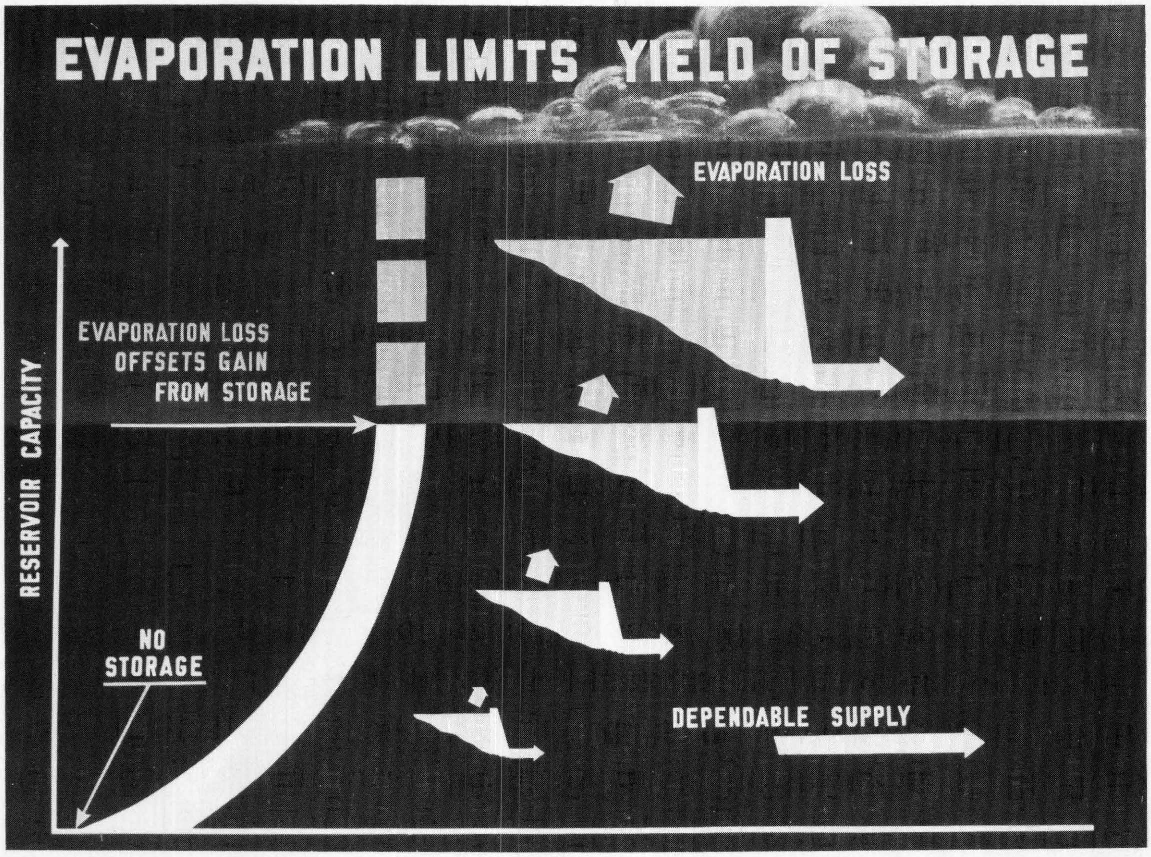

FIGURE 20

Where precipitation is abundant, a plentiful supply of water dilutes the soluble products of weathering, and the solute concentrations in natural water are low. Conversely, where precipitation is light, solutes are concentrated in the natural water. Solutes move with water—they are present in ground and surface waters. Weathering also produces sediment, which is carried in suspension by flowing water. Concentrations of sediment in water differ areally with precipitation similarly to solute concentrations. In response to variable precipitation and geology, the average solute content of raw water for public water supplies differs across the Nation, as shown in figure 24. The differences within any one region may also be appreciable. The data on figure 24 are fairly representative of the better ground and surface waters in each region as a city will seek out the best water supply it can afford.

Because precipitation varies much within a year, the concentration of solutes in streams varies accordingly. This variation, as shown in figure 25, introduces further complications in water use because treatment plants must vary their processes to produce a finished water of nearly uniform, year-round quality. The period of peak demand for water, irrigation for example, may coincide with a period of poor quality. Impoundment in surface reservoirs helps to minimize seasonal variations because of the mixing of high flows of good quality with low flows of poor quality.

The sediment in streams varies with geology, relief, stream velocity, vegetation in the drainage basin, and abundance of flow for dilution. Some geologic formations that are easily eroded are particularly large producers of sediment. An example are the shale deposits of central New Mexico, as shown in figure 26.

Except for the turbidity it causes, sediment carried by streams is seldom a serious problem until man decides to build a reservoir or otherwise slow the velocity of the flowing water. Where sediment concentrations are great, storage space for accumulating sediment must be included in design and cost of reservoirs. (See fig. 23.)

In managing water supplies, a distinction must be made between the *concentration* and the *load* of both dissolved material and sediment. Concentration is the amount of material contained in

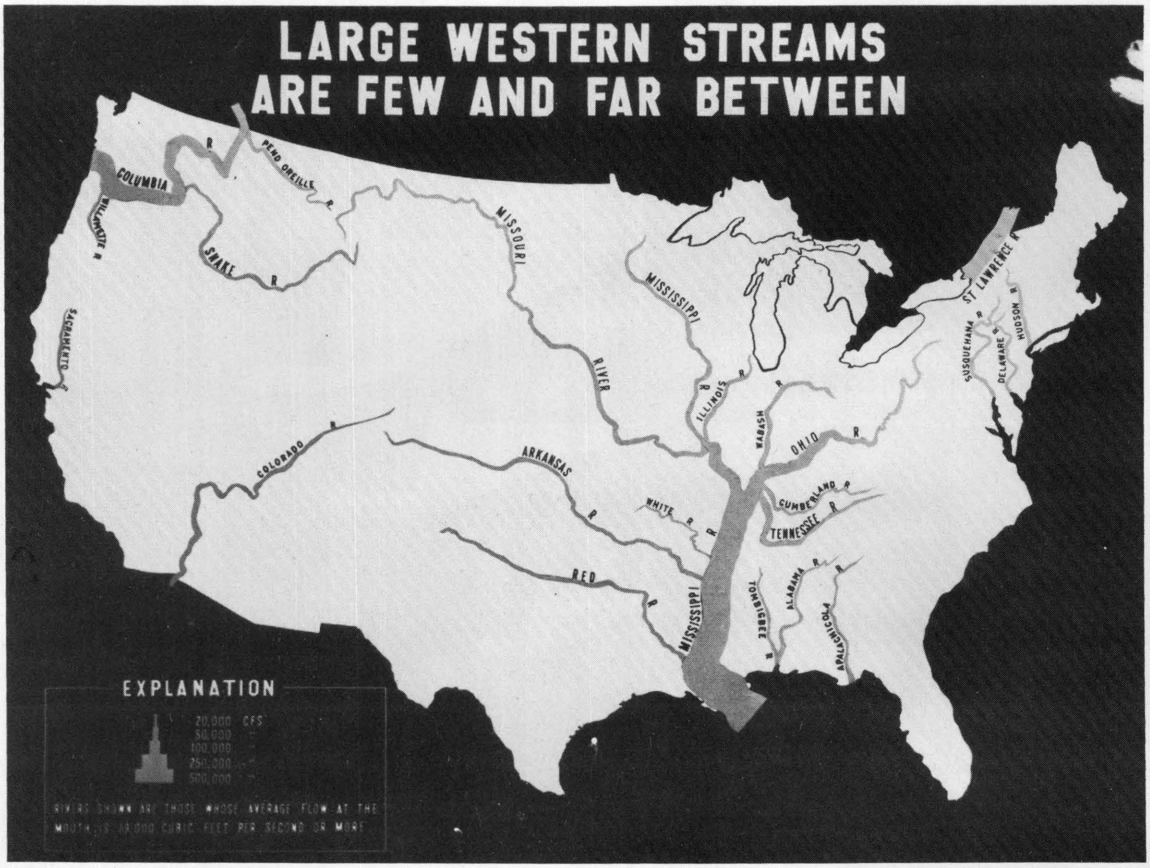

FIGURE 21

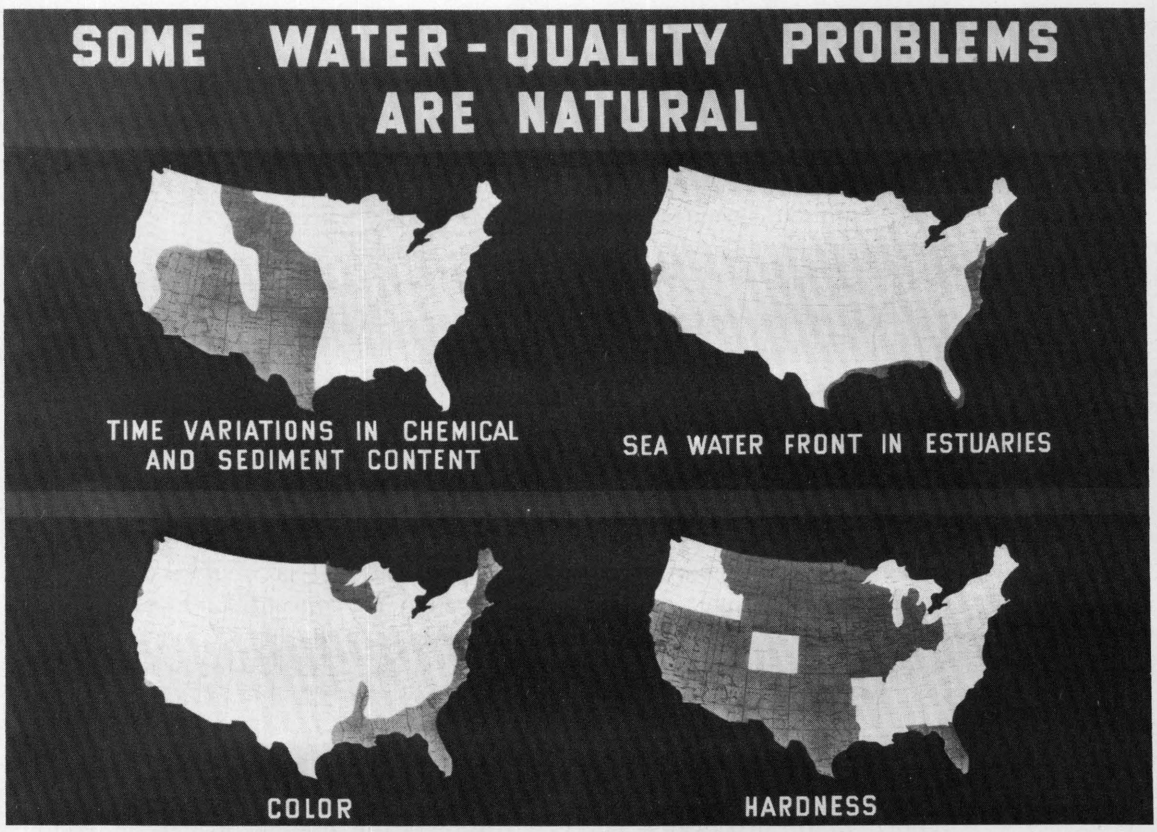

FIGURE 22

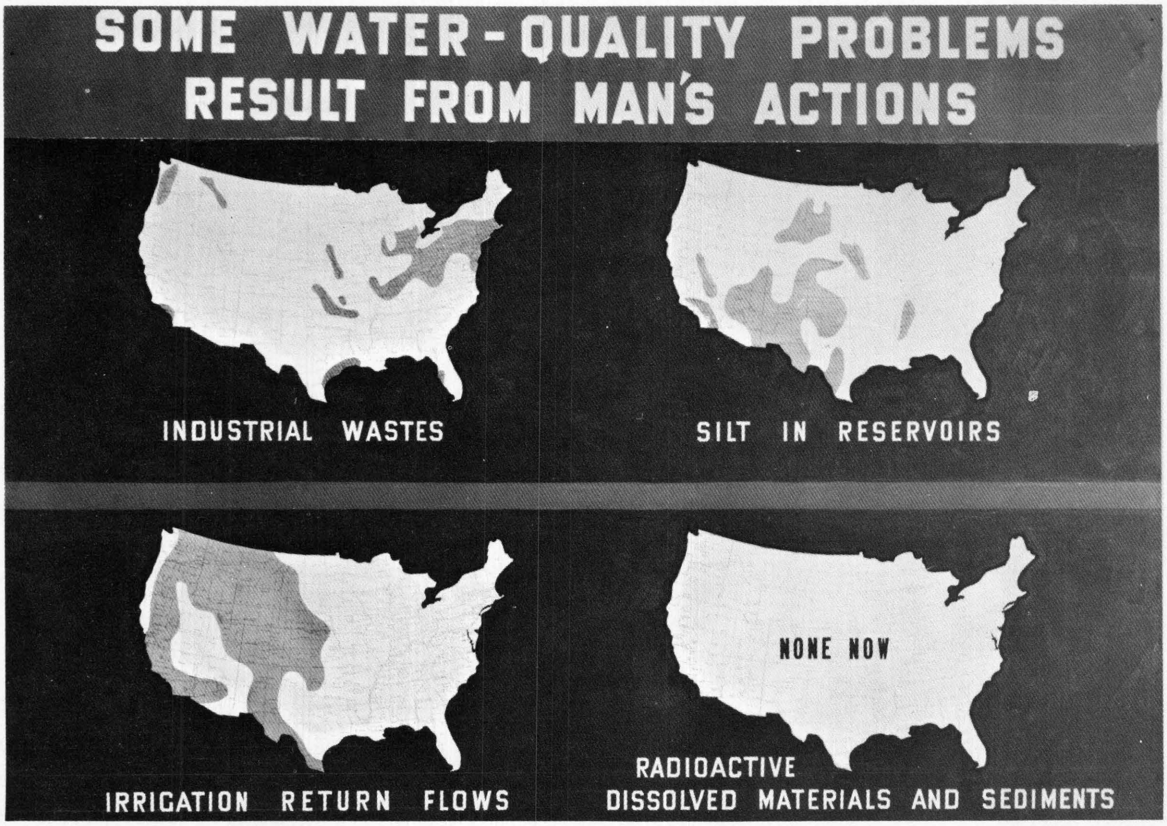

FIGURE 23

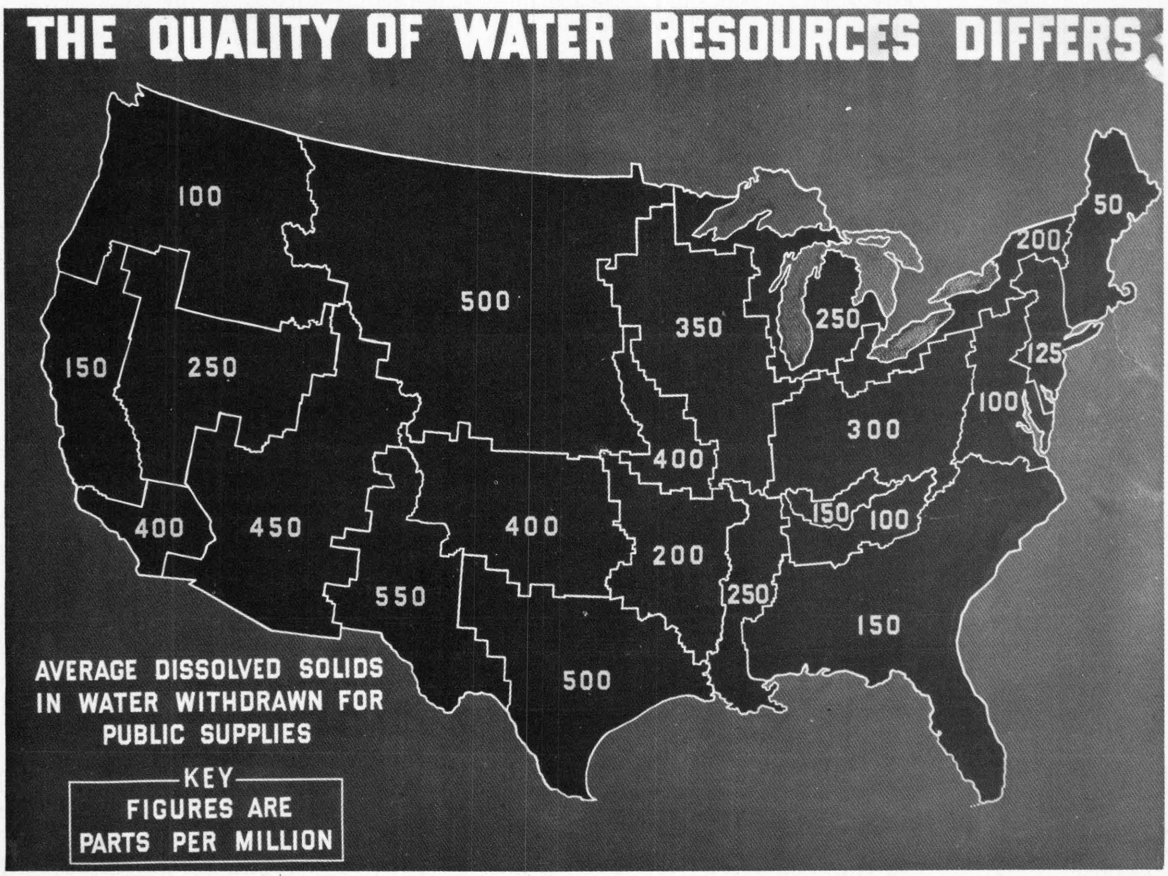

FIGURE 24

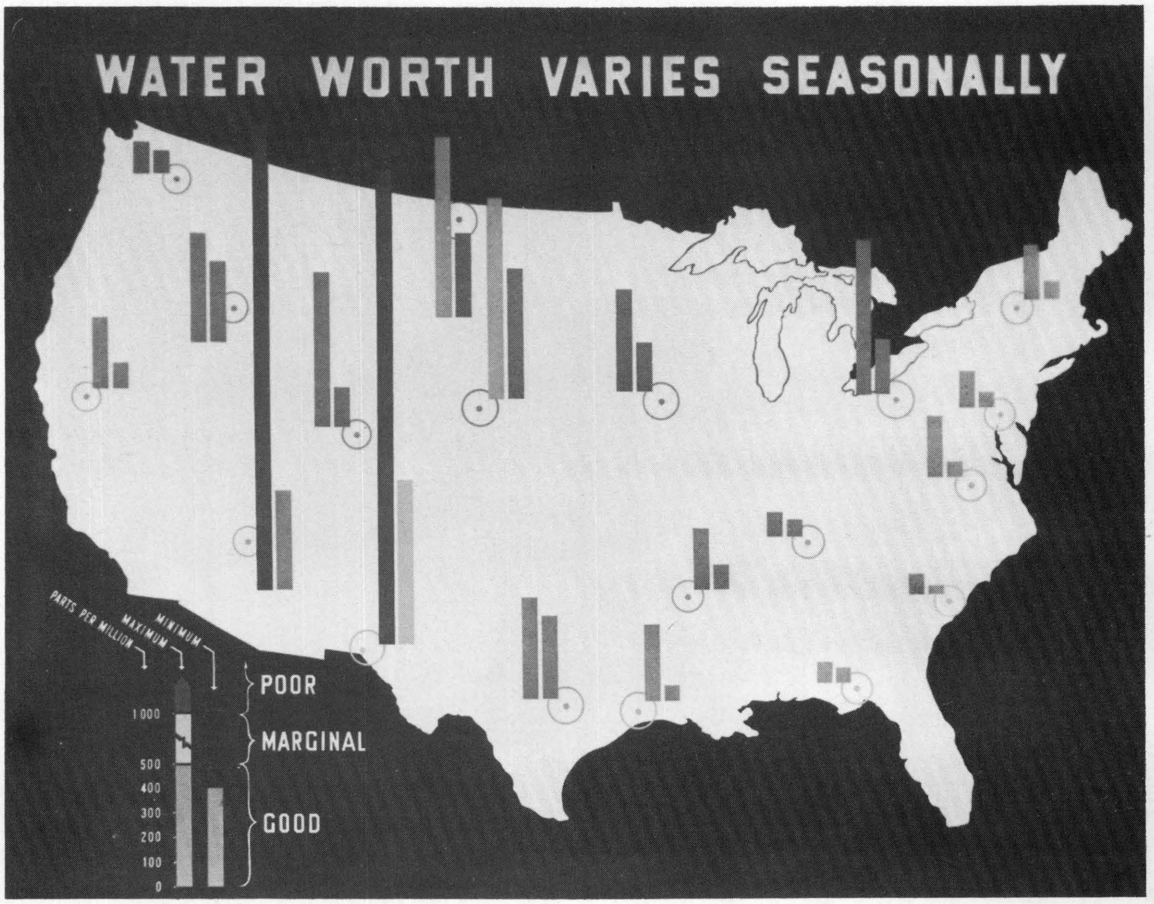

FIGURE 25

a unit volume of water. Load is the amount of material carried in a unit of time by the whole river—the product of streamflow and concentration. For example: A stream flowing at 1,000 cubic feet per second with sediment concentration of 1,000 parts per million is carrying twice the load of a stream flowing at 500 cubic feet per second with 1,000 parts per million sediment. Concentrations are a particular concern to those users, such as municipal waterworks operators, who withdraw a fraction of the streamflow—loads concern engineers planning major storage reservoirs, for storage must be provided for trapped sediment. The solute load of a stream is also the measure that tells how much pollution it can tolerate. Concentrations are qualitative descriptions of a water body, but loads are quantitative.

Many of the Nation's largest cities and industries are located on the sea coast. Sites along the navigable reaches of the rivers are preferred because transportation of raw and finished products is cheap but the water is often too salty for many uses. Accurate definition of the salt-water front and diffuse zone between salt and fresh water, under different conditions of tide and streamflow, is necessary for the economic and efficient location of water-supply intakes.

How does the natural variation in quality of supplies affect the use of water? Some industries can tolerate much dissolved material in process water—others require water with extremely low content of dissolved material. Figure 27 shows the quality of water used in selected industrial processes. Note the excellent quality of water required in the synthetic fiber industry. Dissolved solids are all the salts—measured by weighing everything that is left after evaporating the water from a sample. Hardness is the property related to the amount of calcium and magnesium present. It determines the amount of soap needed for laundries, and is related to the amount of scale that will be formed in a steam boiler.

Water-quality requirements for homes, industries, and irrigated farms vary. About 60 chemical and physical properties, excluding sanitary consideratnios, are pertinent to various uses. In general, domestic supplies must meet the highest standards. As shown on figure 28, the housewife is the least tolerant of poor water quality.

The public can use water of poor quality but

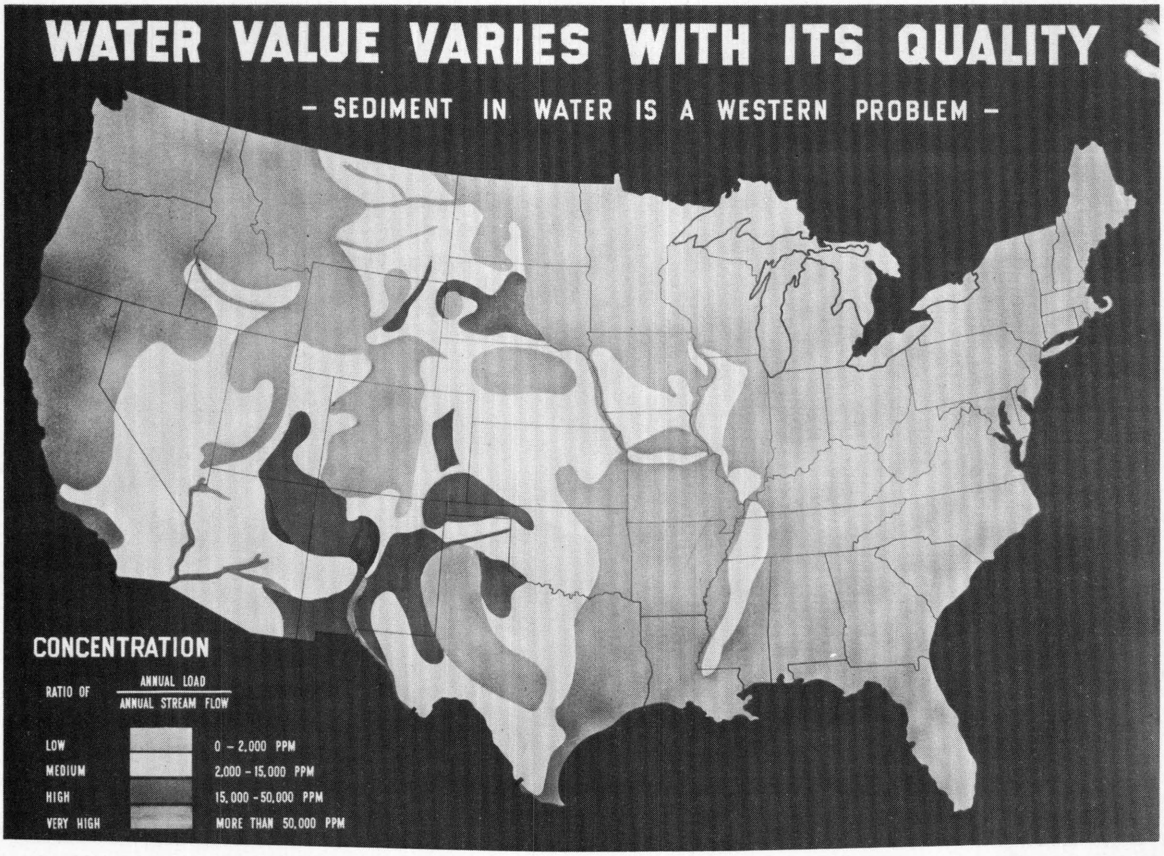

FIGURE 26

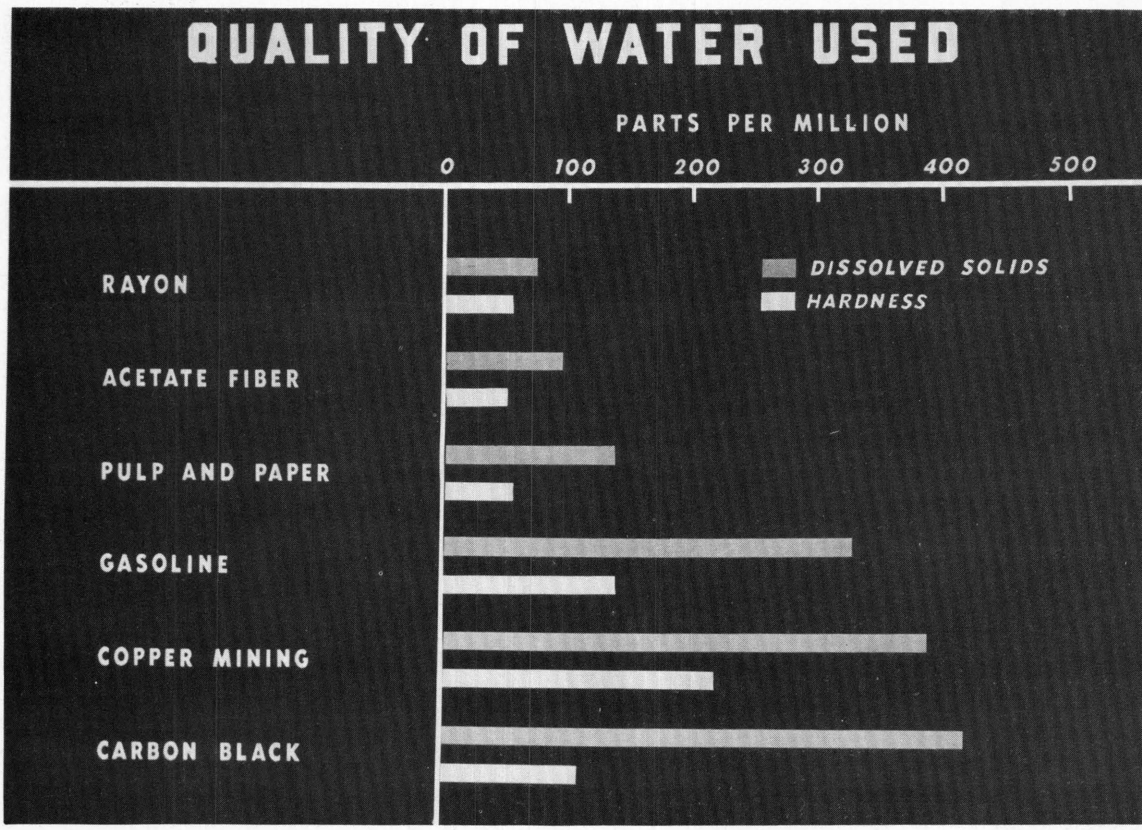

FIGURE 27

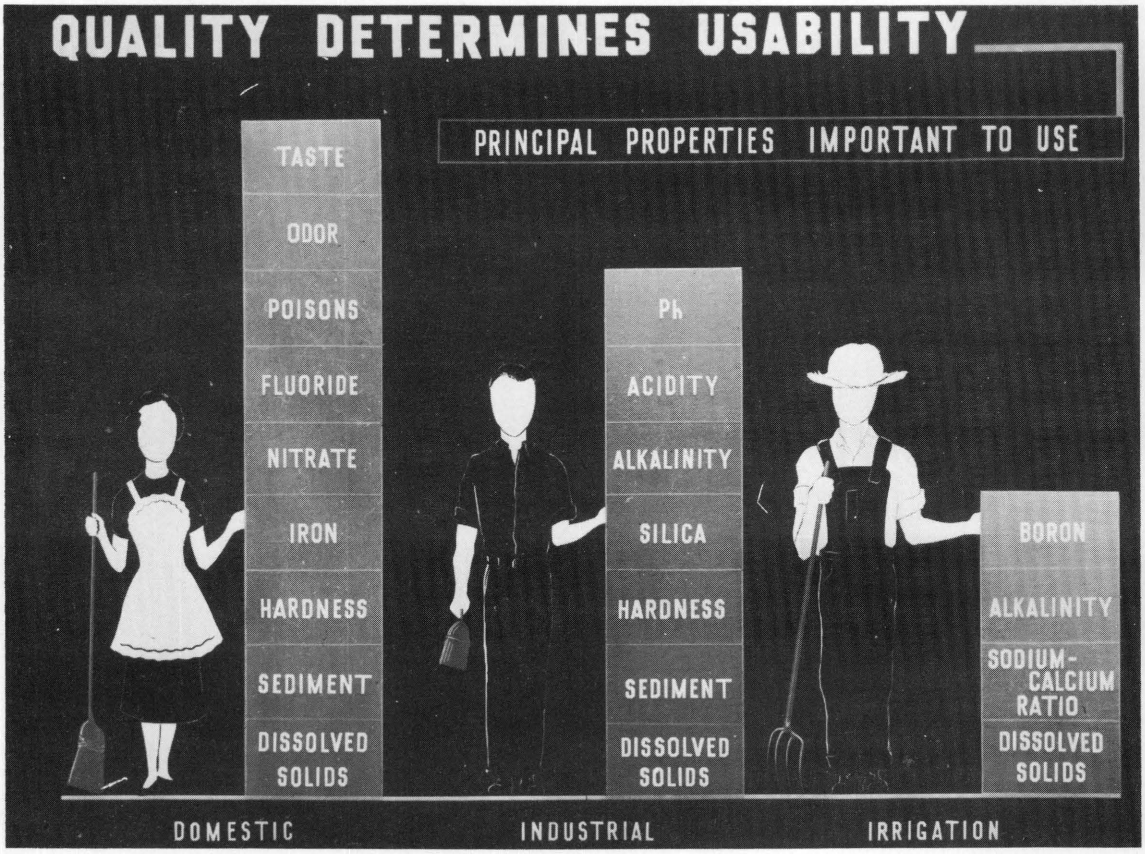

FIGURE 28

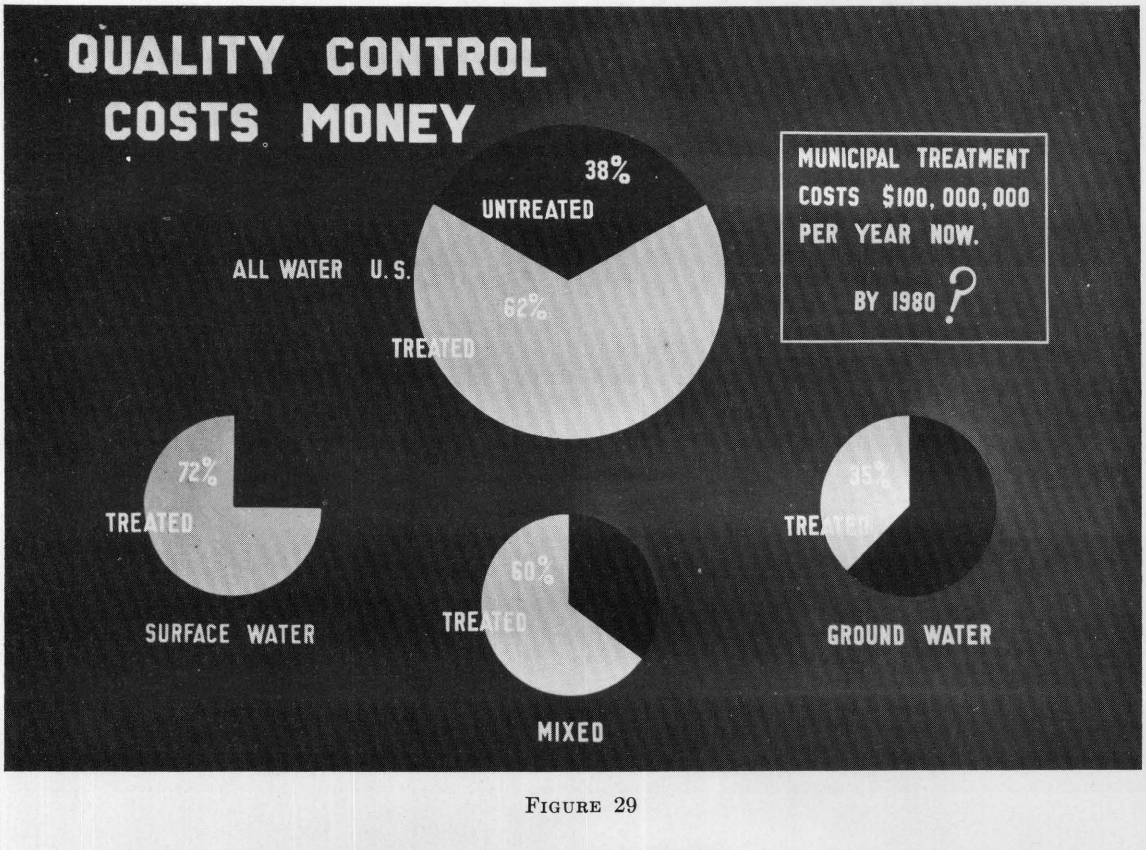

FIGURE 29

prefers to improve the quality before use by appropriate treatment. Much of the water for municipal use receives extensive and costly treatment. The present cost of treating municipal supplies, as shown in figure 29, is $100 million annually. Some supplies are so pure that they require only chlorination—as a sanitary safeguard—before entering the water mains. Others contain so much sediment or undesirable chemical traits that extensive treatment is required to make them satisfactory for use. In parts of the Great Plains during drought periods some municipal supplies withdrawn from household faucets have contained more than 1,500 parts per million of dissolved solids. In contrast to the high quality demands of municipal supplies, some industries use sea water for cooling.

For irrigation, the role of water quality is interwoven with several other factors, as shown on figure 30. Project planners have the know-how for predicting the success or failure of an irrigation project. For example, good crops can be grown on coarse soil with poor water if excess water is applied to flush the accumulated salts from the soil, as in the Pecos Valley of New Mexico. On the other hand, too much good water on tight soil can salinize the soil and cause poor crops. The use of marginal land or marginal water is both a technical and economic problem. Can the development of each new project be justified?

POLLUTION PROBLEMS

To complicate the quality-of-water situation in some areas man's activities worsen the character of the water supply. (See fig. 23.) Pollution is one of the major problems this country must solve. The word "pollution" has different meanings for different people. To some it is raw sewage; to others it is toxic and smelly chemicals; and to the angler it is temperatures too high for trout or bass. To approach the pollution problem realistically, one must include as pollution all the activities of man that in any way degrade the quality of water.

To say that man must stop generating pollution problems is to say that man should stop using water. This is, of course, unrealistic. The transport of wastes from the home, factory, or farm to the sea is a beneficial use of water. As with individual liberties, however, there is a limit to

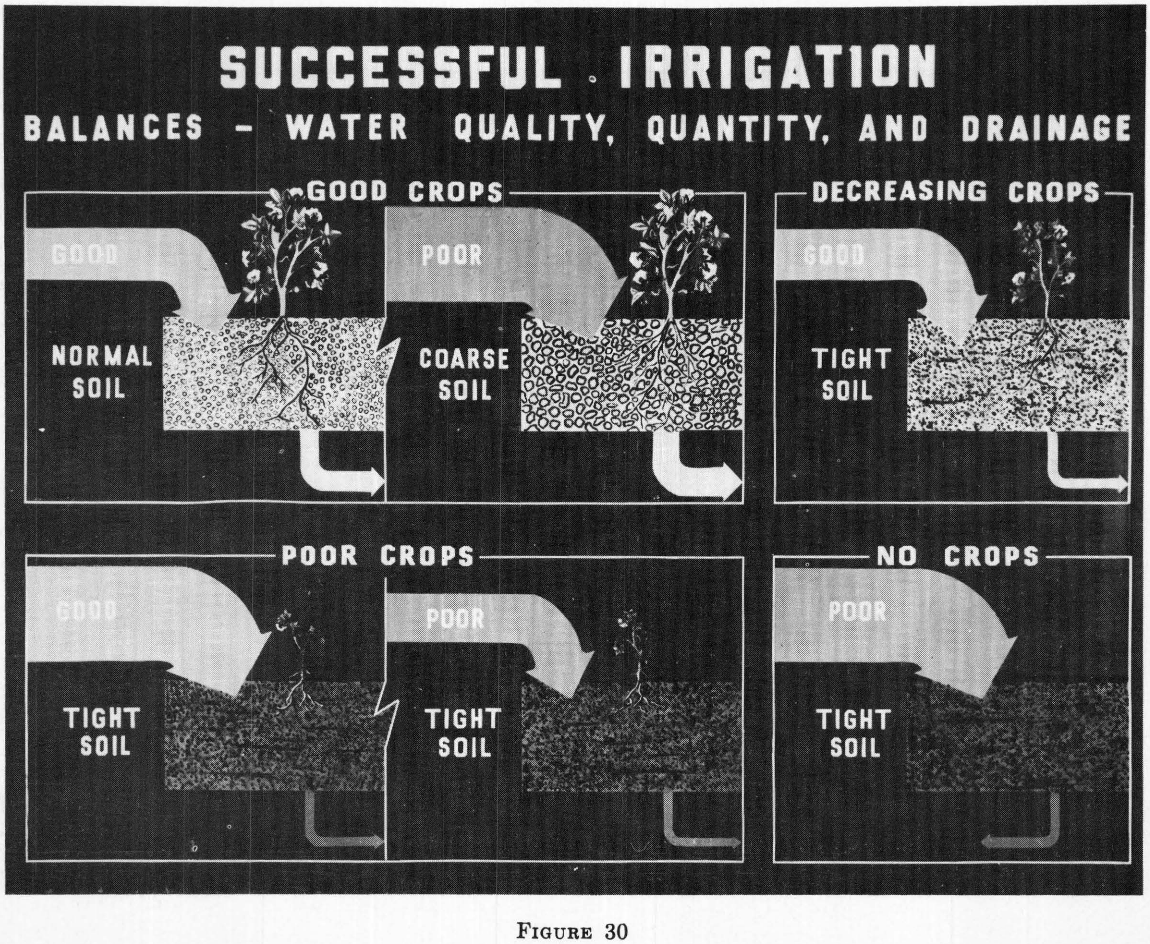

FIGURE 30

which one can go before his actions become offensive to his neighbors and must be regulated for the benefit of the community as a whole. The lack of techniques for preventing pollution limits the degree to which water quality can be improved by regulatory means. The realistic problem is how to handle wastes—not how to stop waste disposal.

Pollutants may enter streams as dissolved or suspended material. Removal of suspended material by municipal treatment plants is an everyday job—removal of dissolved material is costly and is seldom done. Nature modifies organic pollution by oxidation and by bacterial action so that streams do purify themselves somewhat. However, regardless of sewage treatment the end result of using streams to carry away the effluents is a downstream increase in the load of dissolved material. Pollution becomes serious if the stream can't dilute the dissolved load to maintain tolerable concentrations. Then the "bad" situation shown in figure 31 will arise. Attractive streams must have enough flow for adequate dilution of waste. The amount of a chemical already carried limits the amount a stream can receive as waste, additionally, without exceeding a given concentration tolerance. For example, if a tolerance of 100 parts per million chloride is set, a stream carrying 50 parts per million chloride at a rate of 2,000 cubic feet per second has only 1,000 cubic feet per second available for diluting added chloride waste—the other 1,000 cubic feet per second is already "used" or "appropriated" to handle the current chloride load. If the stream had 100 parts per million chloride there wouldn't be any unused water to dilute more chloride waste. As either stream concentration of flow differs, the "net" amount of water available for waste dilution differs. Table 4 was included to demonstrate the varying capacity of a major stream for diluting wastes. For example, to dilute chloride waste to 100 parts per million, 100,000 cubic feet per second unused flow of the Ohio River was available only 8 percent of the time at Newell, W. Va., but 56 percent of the time at Grand Chain, Ill., in 1955. Table 4 shows that at least 3,000 cubic feet per second flow was available for dilution of wastes for all 10-day periods of 1955 at Newell, W. Va. Ten times this flow was available at Grand Chain, Ill.

FIGURE 31

TABLE 4.—*Occurrence of flows available for dilution, Ohio River, 1955* [1]

Flow (thousand cubic feet)	Percentage of time available flow equaled or exceeded amount shown [2]			
	Newell, W. Va. (23,500 square miles)	Ravenswood, W. Va. (39,840 square miles)	Golconda, Ill. 143,900 square miles)	Grand Chain, Ill. (203,100 square miles)
2				
3	100	100		
5	86	86		
7	83	78		
10	72	75		
15	58	58	100	
20	44	60	94	
30	33	39	92	100
50	20	25	67	92
70	14	22	53	81
100	8	14	44	56
150	3	6	33	42
200	0	3	25	33
300		0	14	22
500			8	11
700			0	6
1,000				0

[1] 100 parts per million chloride tolerance assumed.
[2] 10-day periods.

The present industrial pollution situation across the Nation reflects the industrial development of each region and the impact of pollution legislation. The greatest percentage of industries treating wastes to alleviate pollution is in the highly industrialized Delaware-Hudson, Chesapeake Bay, and Ohio River regions, as shown in figure 32. Where pollution is not yet a regional problem, as in the South and Southeast, there is less industrial waste treatment. Some industrial processes, like cooling, cause only heat pollution in streams. This can be eliminated by recirculating water from a pond.

Strange as it may seem, irrigation pollutes streams. This happens because the growing crops use essentially pure water and leave most of the solutes in the return flows that drain from the field to eventually reappear in the stream or ground water. In addition, the water applied to irrigated fields increases the weathering rate and leaches some salt from the soil. As shown in figure 33, a sevenfold increase in salt concentration of the stream resulted from irrigation on one project. Half of the increase in concentration resulted from consumptive use and half resulted from soil leaching.

Ground-water supplies may be polluted, too. Seepage from waste lagoons may reach the ground-water reservoir, as happened in the chromium poisoning of some wells on Long Island. Along our coasts the ocean is always ready to pollute ground-water supplies where man pumps too much water. The pollution process is so gradual that ground-water supplies may be seriously polluted before the problem can be corrected. Once the water in an aquifer is polluted, years may be required for nature to remedy the situation.

When confronted with the problem of handling a radioactive waste as a gas, liquid, or solid, one may either dilute and disperse it, or concentrate and store it. Dilution may be considered for any very small amount of radioactivity (low-level waste). For example, a water solution of 1 part per million strontium 90 yields 0.002 curies per milliliter volume (about one-quarter teaspoon), but this concentration is 2½ billion times the maximum permissible concentration for drinking water. Each teaspoon of this waste would require approximately 2½ million gallons of dilution water to provide a tolerable supply.

Most users of radioactive substances are subject to control, being permitted to release radio activity only in conformance with maximum permissible concentrations set by the National Bureau of Standards, National Committee on Radiation Protection. However, the cumulative effect of multiple low-level radioactive release summarized in table 5 is not now determinate. As streams converge and downstream waste producers contribute radio-

TABLE 5.—*Low-level liquid radioactive waste discharge (to Jan. 1, 1959)*

Site	Approximate volume per year (million gallons)	Total radioactivity released (thousand curies)	Water affected
Argonne National Laboratory.	47		Des Plaines, Illinois, and Mississippi Rivers.
Brookhaven National Laboratory.	120	[1] 2–3.0	Atlantic Ocean.
Feed Materials Production Center.	90		Miami, Ohio, and Mississippi Rivers.
Hanford atomic products operation.	[2] 7,668	[3] 2,096.0	Columbia Rivers.
Knolls Atomic Power Laboratory.	126		Mohawk and Hudson Rivers.
Los Alamos Scientific Laboratory.	14		Rio Grande River.
National Reactor Testing Station.	420	[4] 1.7	Pits and wells, and Snake River.
Oak Ridge National Laboratory.	159	[5] 75.0	Clinch, Tennessee, Mississippi Rivers.
Rocky Flats, Colo	40		South Platte, Platte, Missouri, and Mississippi Rivers.
Savannah River Plant	20	[6].8	Savannah River.
Westinghouse Atomic Power Division (Bettis Field, Pa.)	[7] 137	([1])	Monongahela, Ohio, and Mississippi Rivers.
Total	8,841	2,176.5	

[1] To sea burial in packages.
[2] Includes condenser cooling water not normally radioactive.
[3] Since 1944.
[4] Since 1955 and 1956.
[5] Since 1948.
[6] Since 1955 and 1956.
[7] Includes infiltrated storm water.

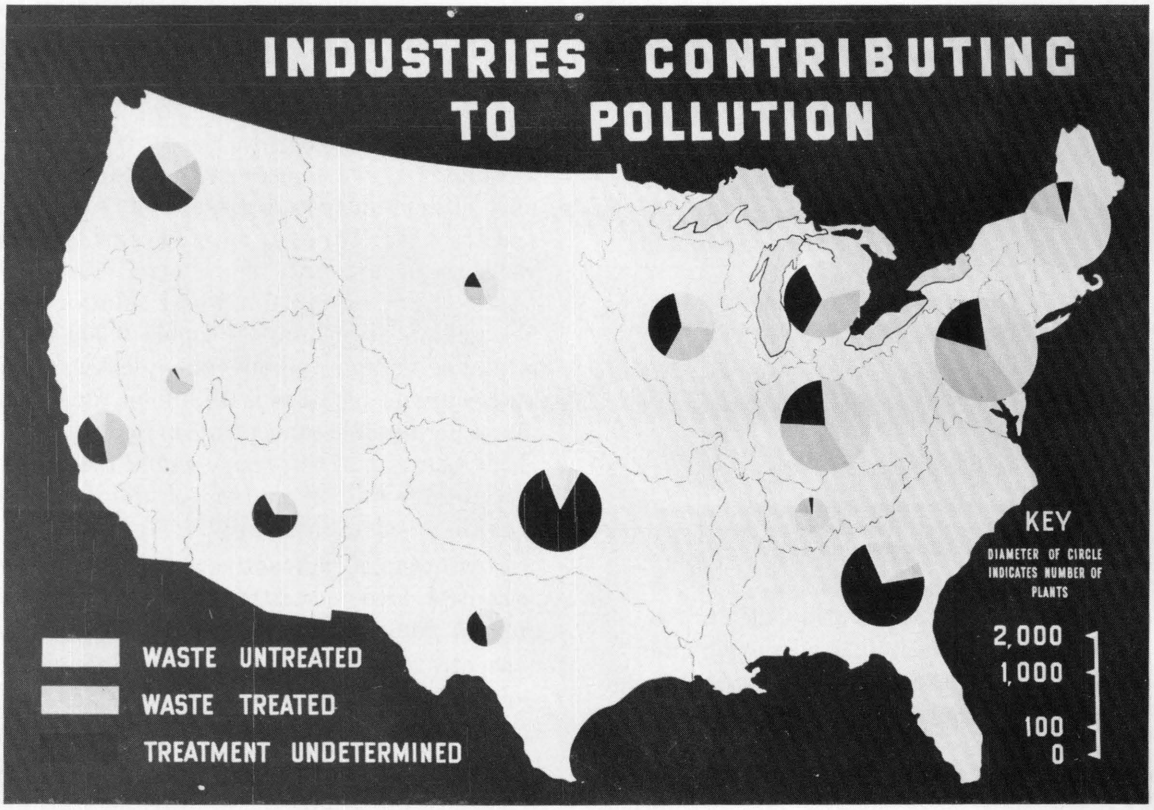

FIGURE 32

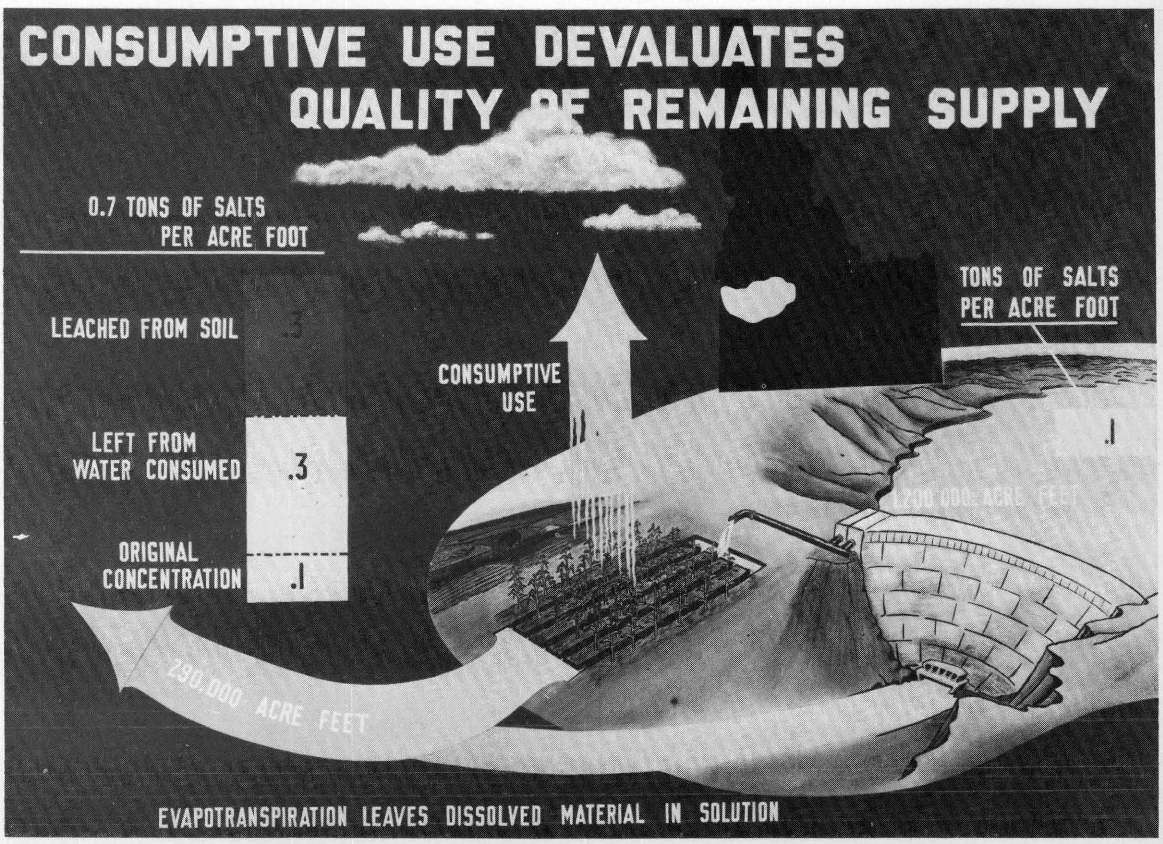

FIGURE 33

activity to a stream, hazards may arise from the accumulation of, or reconcentration of, radioactivity by organisms and sorption by stream sediments.

Natural purification of contaminated water, often assumed for biological contaminants, is not applicable to radioactive waste. Time is the only agent capable of destroying radioactivity. This time factor makes discharge or seepage of wastes into the ground dangerous. If waste which has a long life reaches a used or usable ground-water aquifer the water may remain contaminated for many years.

In terms of cost, dilution is the most attractive method of disposal, as is done in the uranium milling operations listed in table 6, but it is not generally practical for large amounts of waste. The only alternative is complete storage of wastes in containers or in a natural environment with proven safety. Storage must be in such a place that the escape rate to outside environment is so slow that no hazard will arise. Projected accumulated volumes of high and intermediate-level waste are:

Year:	*Waste stored (million gallons)*
1970	6. 5
1980	36. 0
1990	110. 0
2000	300. 0

Quantities of waste from limited research operations and routine power reactor operations often can be dispersed. However, use of large-scale power reactors in urban areas may be restricted because of the hazard of accidental (earthquake, sabotage, warfare) release of normal contained fission. The location of civilian power and propulsion reactors are given in table 7. The much larger quantities of radioactivity resulting from nuclear reactor fuel reprocessing and plutonium production should never be released.

TABLE 6.—*Rivers receiving wastes from uranium milling operations*

River	Location	Radioactivity ($\mu\mu c/1$)[1]	
		Gross alpha	Gross beta
Animas	Above Durango	2	32
	Below Durango	34	26
Colorado	Above Rifle	0	7
	Below Rifle	49	15
	Above Grand Junction	13	22
	Below Grand Junction	183	295
San Miguel	Above Naturita	10	16
	Below Naturita	148	61
	Above Uravan	92	46
	Below Uravan	4, 700	5, 496
San Juan	Above Ship Rock	220	369
	Below Ship Rock	170	204
Jordan	Above Mill	5	28
	Below Mill	23	51

[1] Micro-micro (1 million millionth—10^{-12}) curies per liter.

TABLE 7.—*Civilian power and propulsion reactors*

Location	Name and/or owner	Startup	Water affected
	OPERABLE		
Shippingport, Pa.	Shippingport Atomic Power Station.	1957	Ohio River.
	BEING BUILT		
Morris, Ill.	Dresden Nuclear Power Station.	1959	Illinois and Mississippi Rivers.
Indian Point, N.Y.	Consolidated Edison thorium reactor.	1961	Hudson River.
Lagoona Beach, Mich.	Enrico Fermi Atomic powerplant.	1960	Lake Erie.
Rowe, Mass.	Yankee Atomic Electric Co.	1960	Deerfield and Connecticut Rivers, and Long Island Sound.
Elk River, Minn.	AEC and Rural Cooperative Power Association.	1961	Mississippi River.
Hallam, Nebr.	Hallam nuclear power facility.	1962	Missouri and Mississippi Rivers.
	PLANNED		
Piqua, Ohio	AEC and city of Piqua, Ohio.	1961	Miami, Ohio, and Mississippi Rivers.
Sioux Falls, S. Dak.	Northern States Power Co.	1962	Missouri and Mississippi Rivers.
Parr, S.C.	Carolinas-Virginia Nuclear Power Association, Inc.	1962	Broad, Congaree, and Santee Rivers.
Humboldt Bay, Calif.	Humboldt Bay project	1962	Pacific Ocean.
Big Rock Point, Mich.	Consumers Power Co.	1962	Lake Michigan.
Florida	East Central and Florida West Coast Nuclear Groups.	1963	
Peach Bottom, Pa.	Philadelphia Electric Co.	1963	Susquehanna River.

It is practically impossible to devise any waste-collection system efficient enough to attain 100 percent cleanup. Therefore, even though an ideal goal may be to discharge materials containing *no* activity, in practice this is not possible. Guided by health and safety considerations, realistic disposal levels that can be attained at reasonable cost must be established. The levels will vary from place to place and are dependent primarily upon environmental factors.

FLOOD PROBLEMS

Floods—too much water—are a problem in many parts of the country. The history of many valleys has started with settlement on the level flood plain along the main stream. The settlers soon learned that the stream varied through a wide range of discharge. More than half the year it barely covered its bed, but occasionally it overflowed its banks, as shown in figure 34, and flooded those living near it on low ground. After being flooded several times, the settlers built small levees to protect their property but invariably the levees were eventually overtopped. Group action by levee districts, counties, States, and finally the Nation has been taken to provide flood protection works. However, despite the money spent for flood protection, floods continue to be a national problem. Estimated flood damage for some major

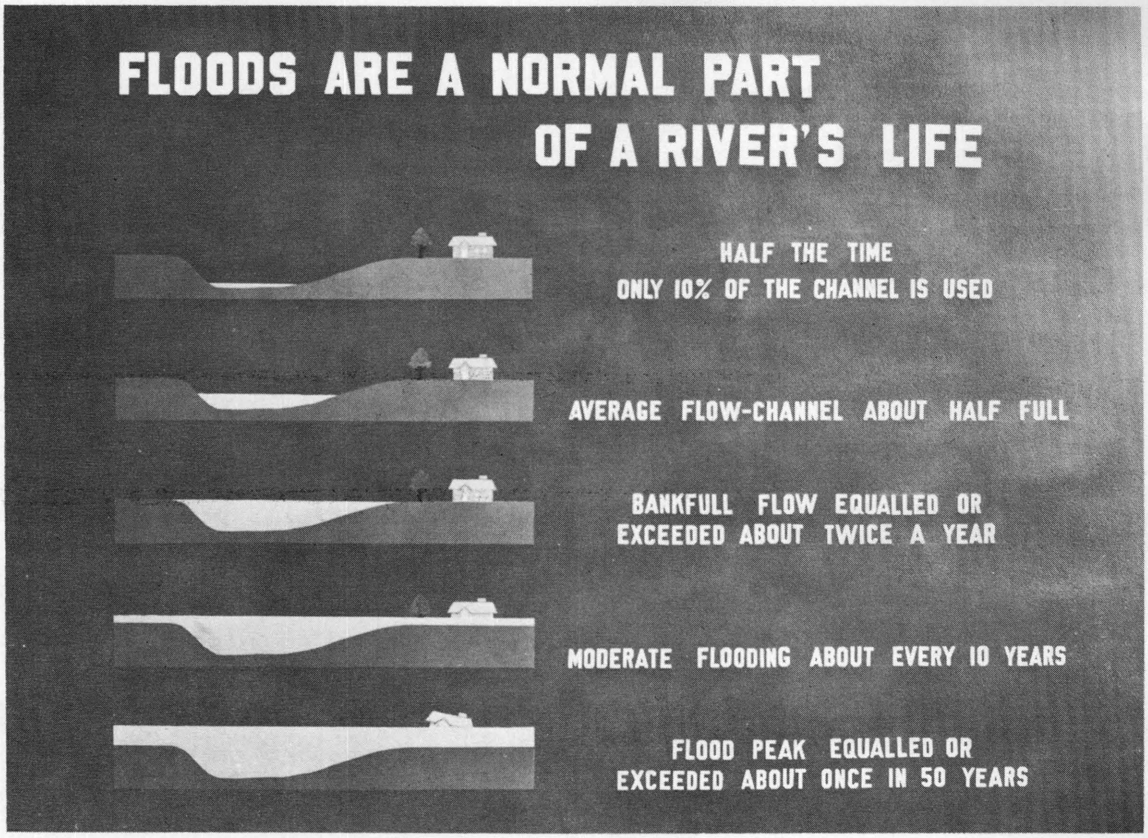

FIGURE 34

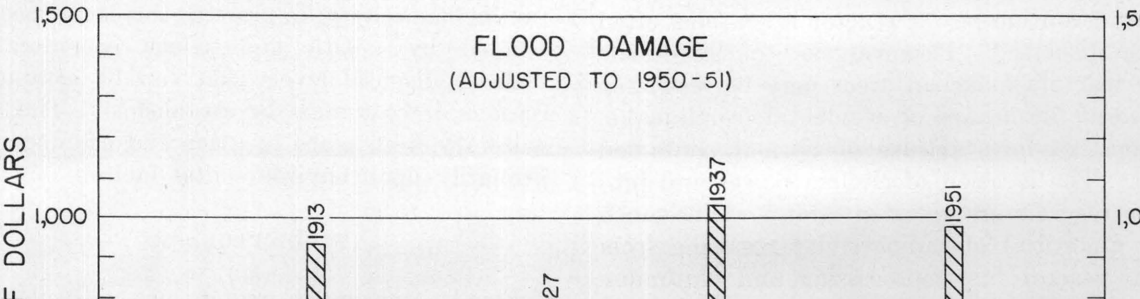

FIGURE 35

floods is shown in table 8 and estimated annual flood damage is shown in figure 35. Annual flood damage is greatly affected by the infrequent "catastrophic" flood. Because flood plains have many attractive features, man overlooks or chooses to ignore the threat of flood damage and uses the flood plain for homes, industry, and agriculture. Complete protection from floods is ordinarily not provided along most rivers because a system adequate to pass the infrequent, extremely high floods is too costly. Partial protection from flooding encourages greater use and development of the flood plain. When a rare flood overtops the levees, property losses are large because occupancy of the flood plain has offset gains from flood control and annual flood damage in the country remains essentially constant, as shown in figure 36.

TABLE 8.—*Estimated damage caused by some major floods*

Year	Location	Estimated damage in millions of dollars (1950–51)
1927	Lower Mississippi River	$300
1936	Ohio River	240
1937	do	750
1948	Columbia River	110
1951	Kansas-Missouri Rivers	900

The succession of higher and higher floods is sometimes erroneously explained as being the result of deforestation and tillage. Flood plains which were formed thousands of years before civilized man came to this country show that floods are not a new experience. Floods are natural. It is the function of a river to carry away water that drains from the land. Average precipitation in this country is 30 inches annually, of which 21 inches are returned to the atmosphere as evapotranspiration and 9 inches are left for the rivers to carry away. (See fig. 3.) The average runoff of 9 inches is not uniformly distributed throughout the year or from year to year—75 percent of the time flow is less than average. The erosive power of a river carves a channel large enough to carry the most frequent flow. A typical river channel, shown in figure 34, will flow half full at average discharge and flow bankful at discharges that occur once or twice a year. Occasionally heavy rains or melting snow contribute a flow greater than bankful capacity of the river channel. Then the flood plain, which the river built for that purpose, carries the flow in excess of channel capacity. The flood plain is an integral part of a river and serves in the same manner as overload springs on an automobile that is used only occasionally to pull a heavy house trailer.

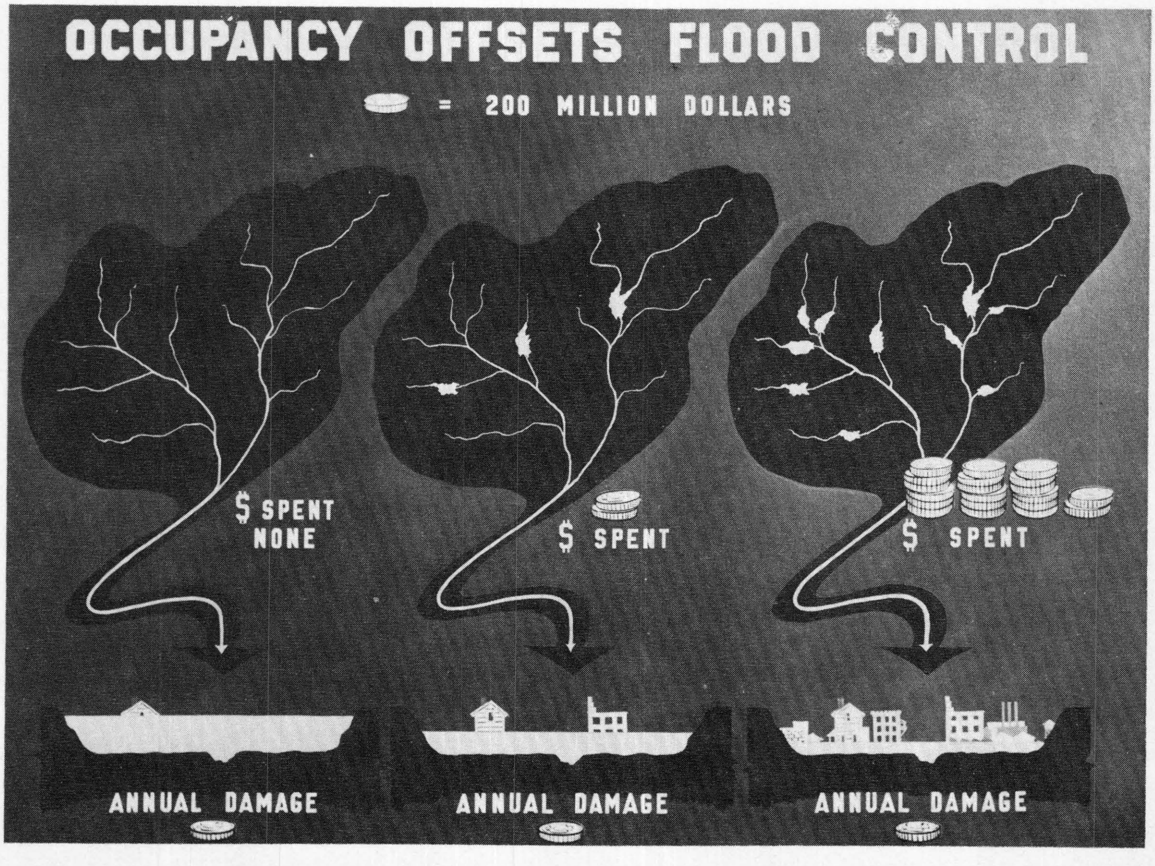

FIGURE 36

The average annual runoff of 9 inches if distributed evenly throughout the year would be 0.025 inch of runoff per day. It is this small flow that determines the sizes of river channels. In contrast to the small daily runoff that builds river channels, precipitation of 2 to 4 inches per day occurs occasionally over large areas. Maximum 24-hour precipitation recorded for typical locations is 8.78 inches at St. Louis, 14.01 inches at New Orleans, 4.08 inches at Pittsburgh, and 7.24 inches at Sacramento. Precipitation of those magnitudes occurs only over small areas during one storm. Storms lasting a few days to several weeks and covering large areas may have 10 to 15 inches of precipitation. Although only part of the precipitation runs off as streamflow (some of it infiltrates into the soil), such storms generate more runoff than can be contained in natural channels. For example, the Bourbeuse River at Union, Mo., carries an average runoff of 0.03 inch per day from its drainage area of 808 square miles but during a flood in June 1945 it carried 1.27 inches of runoff, or 42 times its average, in a single day. The Bourbeuse River had to use its flood plain to carry part of that flow. The recordbreaking 1937 Ohio River flood was caused by 12.85 inches of precipitation falling on a watershed covered with snow equal to 0.1 inch of water. Flood runoff amounted to 8.9 inches. Rains that saturate the soil before the flood-producing storm occurs are part of the stage setting for most floods. The extremely high precipitation rates associated with catastrophic floods make any of man's land treatment measures futile to stop them.

Floods in any river basin have a characteristic frequency at which they may be expected to occur, the larger the flood the less frequently it can be expected to occur. A flood frequency graph for the Kansas River at Topeka, Kans., is presented in figure 37. The disastrous flood of 1951 at Topeka is shown to have a recurrence interval of 100 years, which means that over a long period of time the average length of time between floods the size of that in 1951 would be 100 years. This does not mean that the next similar flood at Topeka will be in 2051, and then another in 2151, but rather that every year there is 1 chance in 100 that a flood equal to or greater than the 1951 flood may occur. Although the size of floods that will occur next year cannot be forecast, we can compute the probability that a flood of a given size may occur next year. The longer man lives in an area, the more years are available to experience floods with larger recurrence intervals—this explains the *apparent* increase in size of floods with continued occupancy of an area.

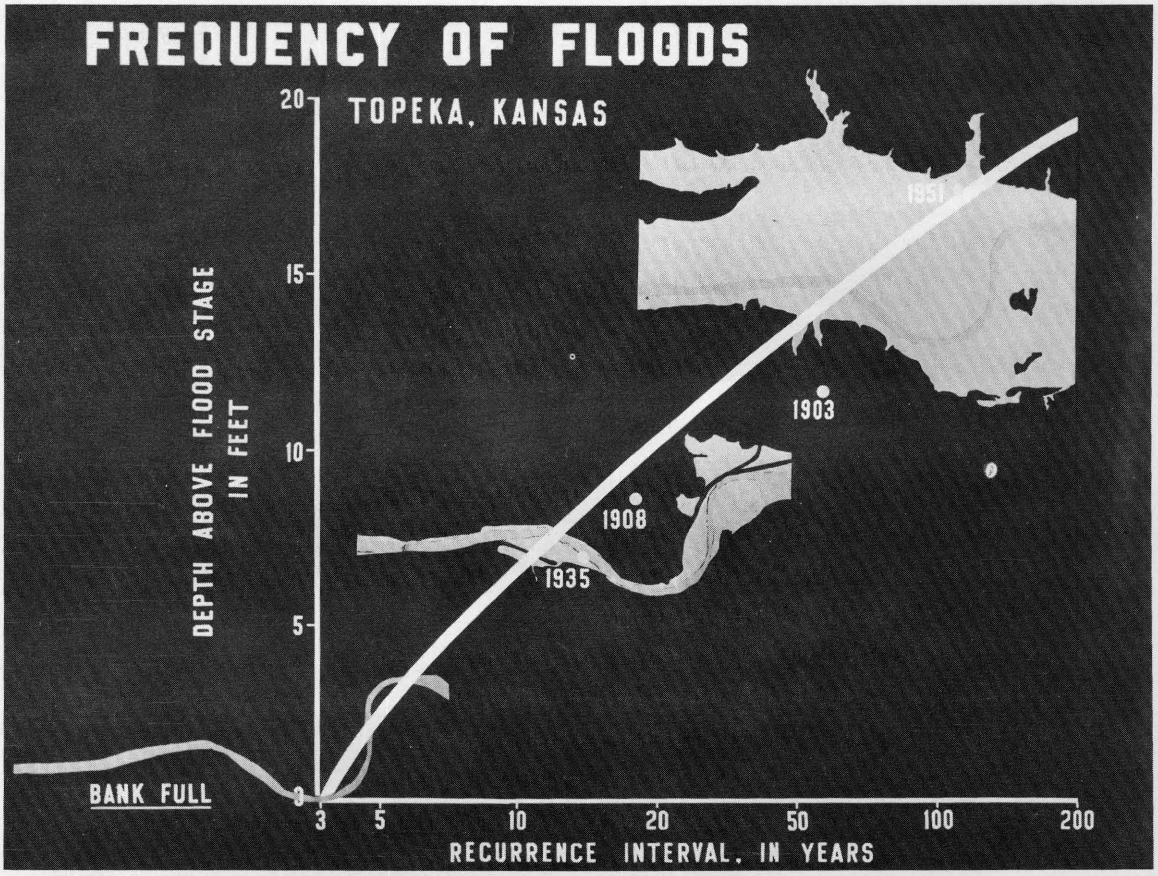

Figure 37

Works to prevent flood damage can be grouped into three categories: (1) channel improvements that increase the carrying capacity of the stream, (2) levees to confine the flow, and (3) reservoirs to store storm runoff until the stream can carry it without flooding. Land treatment works have not been listed because their ability to decrease major floods has not been fully demonstrated. Modern flood prevention programs usually combine the three categories. Channel improvement ordinarily is used to remove "bottlenecks" that impede the flow near cities. Levees have until recently been by far the most common flood-control structure but they have two disadvantages: (1) they increase the elevation of water in the confined channel for any given flood flow because the flood plain is no longer available to help carry the flow, and (2) the natural storage on the flood plain, which is important in reducing flood crests as they move downstream, is lost. Property to be protected must have a high valuation if complete flood protection by levees is to be economical. The rich industrial city of East St. Louis and surrounding communities in Madison and St. Clair Counties, Ill., that are on the low flood plain of the Mississippi River are protected by a levee system which has withstood all major floods with ease. The benefits from complete flood protection on farmland alone or even residential areas could not justify such a costly project.

Present trend in planning for flood control is to use large storage reservoirs, on the main streams, to hold back part of the storm runoff so the leveed channels downstream will not be overtaxed. Reservoirs designed solely for flood control are emptied as soon after each storm as the river downstream can carry the water without overflowing. Multipurpose reservoirs, instead of storing water for just one purpose such as flood control, retain some of the floodwater for later release possibly for power development, water supply, navigation, irrigation, or to dilute wastes. A multipurpose reservoir must have greater capacity than a flood control reservoir at the same site if it is to provide the same protection. Bonny Reservoir on the South Fork of the Republican River in eastern Colorado has 129,000 acre-feet of storage for flood control, 24,000 acre-feet for irrigation, and 16,000 acre-feet for sediment control. John Martin Reservoir on the Arkansas River has 280,000 acre-feet of its capacity alloted to flood control and 395,000 acre-feet for irrigation.

Figure 19 shows that control of the flow of a stream by reservoirs to provide flood protection, or for any other purpose, is subject to the law of diminishing return. Each additional increment of control that is provided requires more storage than the previous increment. The ideal way to regulate a stream for flood control and utilize water might appear to be a plan incorporating enough storage to permit flow in the stream to be held at its average rate of flow. However, that is not practical because the amount of storage needed becomes tremendous as regulated flow approaches the average flow.

One important benefit derived from storage of floodwater is likely to be overlooked—that is the improvement in chemical quality of the water supply. In many western streams chemical quality of the low flow is relatively poor and chemical quality of the floodflows is good. Storing the floodwater of good quality dilutes the water of poor quality that would otherwise be available most of the time and thereby provides a supply that is improved and more uniform in quality throughout the year. During 9 months of 1954, Colorado River water flowing into Lake Mead contained over 1,000 parts per million of dissolved solids, and most of that time the concentration was at least 1,300 parts per million. In that same year Colorado River water leaving Lake Mead below Hoover Dam averaged only 677 parts per million of dissolved solids. Without Lake Mead most of the high flows consisting of good quality would travel unused into the Gulf of California, and only the water of poorer quality would be available 75 percent of the time.

Solving the Nation's Water Problems

The Nation must solve the six major water problems if expansion of the United States is not to be hampered. The Nation can build on the progress already made—few innovations will be necessary. Individuals, industries, cities, States and the Nation have already made great progress in solving major water problems. The public can insure adequate water supply by more skillful management of our water resources, better integration of regional supply-demand relationships, and continued identification and solution of new water problems.

Much progress has already been made on solving problems of supply and variability. Public and private groups have constructed a great amount of surface storage to increase dependable streamflows. As shown in table 9, there was in 1954 a total usable reservoir capacity of 278 million acre-feet in the United States. This total does not include thousands of ponds and artificial lakes having less than 5,000 acre-feet capacity. Table 9 shows that in the Colorado River and upper Missouri River regions constructed reservoirs have a usable capacity 2.3 times the average annual volume of water supply. In those regions several additional large reservoirs have been constructed since 1954 or are in construction. Yet the ultimate development of storage reservoirs in the Colorado and upper Missouri regions may be many years away. In other regions development of more dependable supplies by constructing reservoirs is only beginning.

Future reservoir construction may be justifiable economically and hydrologically but many complicating factors will make decisions for specific projects difficult. In general, following development of the most economical and necessary reservoir sites those that remain might be expected to cost more per unit of storage. However, experience in the Tennessee region does not verify that expectation. Figure 38 shows the cumulative costs (adjusted to 1956 prices) of reservoir construction in the TVA plotted against cumulative capacity in acre-feet of storage. Note that there is no trend to increased costs for more recent construction. Advances in construction equipment and techniques have made it possible to keep unit costs of reservoir capacity from rising.

TABLE 9.—*Usable capacity of reservoirs of 5,000 or more acre-feet, 1954*

Region	Usable capacity (million acre-feet)	Ratio of storage to average annual supply
New England	9.0	0.1
Delaware and Hudson Rivers	3.1	.1
Chesapeake Bay	.9	[1].1
Southeast	16.4	[1].1
Western Great Lakes	1.2	[1].1
Eastern Great Lakes	.5	[1].1
Ohio River	5.7	[1].1
Cumberland River	6.4	.4
Tennessee River	15.0	.3
Upper Mississippi River	4.3	[1].1
Upper Missouri River	74.8	2.3
Lower Missouri River	1.2	[1].1
Upper Arkansas-Red Rivers	7.3	.6
Lower Arkansas-Red and White Rivers	26.8	.3
Lower Mississippi River	4.5	.1
Upper Rio Grande and Pecos Rivers	3.3	.8
Western Gulf	11.2	.2
Colorado River	35.1	2.3
Great Basin	4.1	.4
South Pacific	1.8	1.2
Central Pacific	16.4	.2
Pacific Northwest	28.9	.2
United States	278.0	.2

[1] Less than.

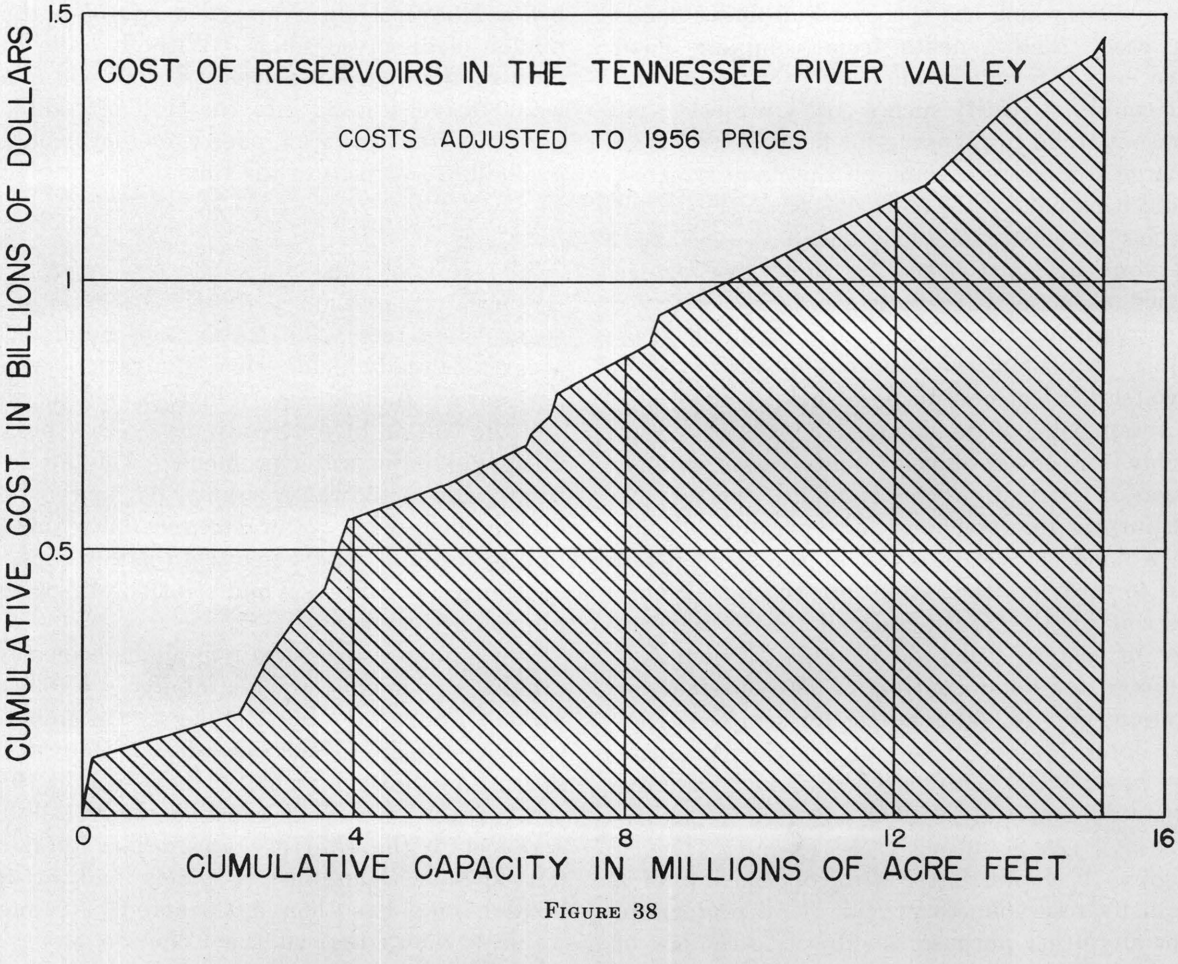

FIGURE 38

Reservoirs constructed for multiple purposes such as water supply, flood control, recreation, and hydroelectric power may prove economically and hydrologically feasible although a small project built to satisfy only one purpose would not be feasible. In the future reservoirs will probably be justified on the basis of several purposes, including water supply. Can benefits from recreational facilities developed in a storage reservoir be assigned a value? How much will flood control storage improve low flows and water quality? These are typical questions that need to be answered in the economics of reservoir planning.

Streamflow supplies may be increased by measures other than storage operation. Particularly in the arid and semiarid parts of the Nation much water that is now wasted can be saved for use. Water wasted by nonbeneficial plants and by evaporation from water surfaces totals 43 million acre-feet per year in 17 Western States. As shown in figure 39, about half the loss is caused by phreatophytes—water-loving plants—and about half is caused by evaporation from surfaces of streams, lakes, and reservoirs. The combined loss in the 17 States is sufficient to irrigate at least 20,000 square miles of farmland. Most of the loss will always exist; however, much water can be saved by careful location of reservoirs and by destruction of phreatophytes. Research into methods for suppressing evaporation from water surfaces may eventually develop inexpensive materials that will work.

Storage of water in aquifers has many advantages over storage in surface reservoirs. One advantage is that, if the water table is maintained below the root zone, the water will not be subject to losses from evapotranspiration. Another advantage is the low and uniform temperatures when withdrawn from aquifer storage. Also, ground water may generally be withdrawn at the point of use thus eliminating expensive distribution systems. Another advantage of underground storage is that the ground above the area may be used for farms, cities, or factories.

A few areas are already making skillful use of aquifer storage. Wells on Long Island are pumped to provide cooling water for air conditioning and the used water is returned to the aquifer through recharge wells. Supplies of ground water are sure to be developed for future demands in the regions where natural recharge is plentiful and aquifers can store and yield large quantities of water. The vast Coastal Plain extending from Long Island to Texas is one

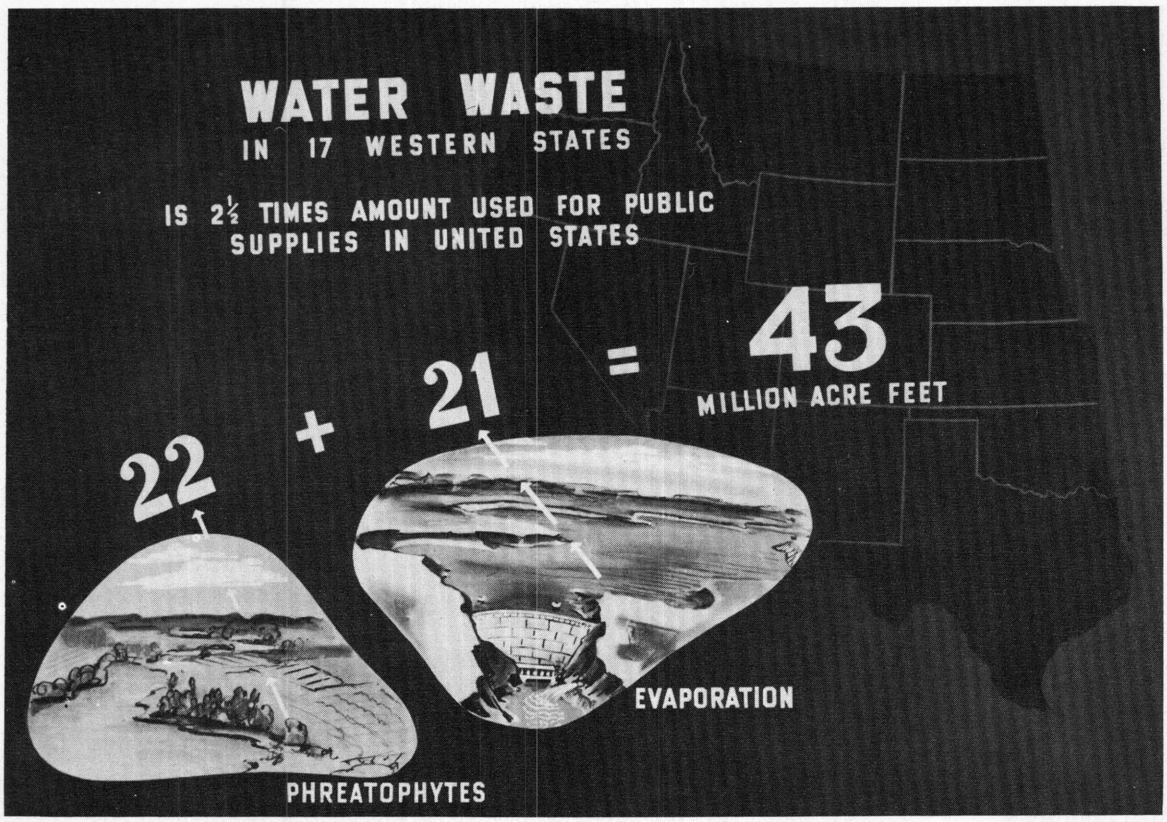

FIGURE 39

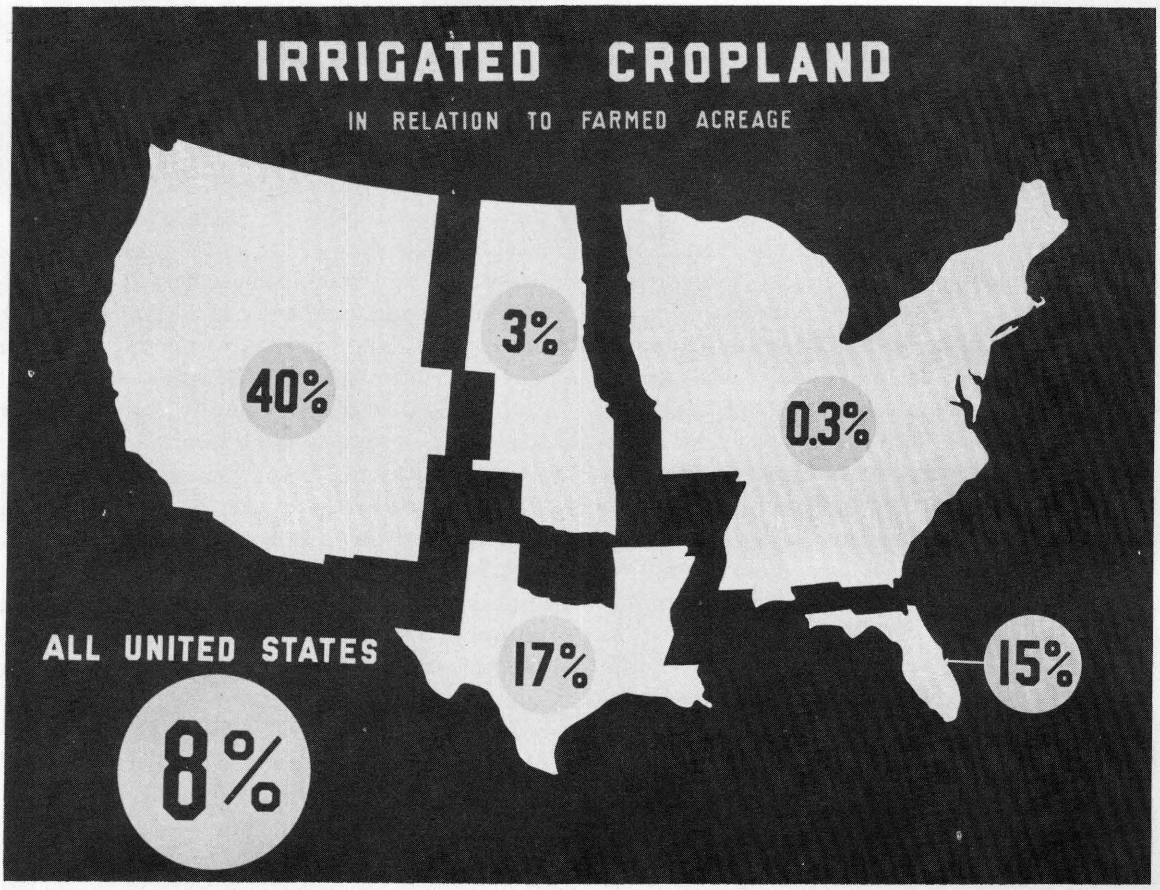

FIGURE 40

tremendous but, as yet, largely untapped underground reservoir.

From a nationwide, or even regionwide, standpoint, much can be done to "stretch" our water resources by properly matching supply with demand. It is poor economy to use a high quality fresh water for an industrial process that can readily use a saline supply. Matching supply with demand also involves seasonal considerations. If supplemental irrigation is widely used in the humid Eastern United States, the peak water demand created by it may exceed the supplies available from streams without resorting to storage because streamflow is low during the summer. Where good ground-water supplies are available they may fill the need. At present irrigated land in the East is only a small part of the farmed land, as shown on figure 40. Irrigation may become widespread in the East where supply is sufficient for a great amount of irrigation, but storage will be necessary to hold winter flow for summer use.

Since World War II, manufacturing has grown rapidly in the West. As shown in figure 41, western manufacturing increased four times during the period 1939 to 1956, while farm production doubled during the same period. Because the value of manufactured products is generally many times greater than the farm products produced from the same water, economic considerations would favor the use of water by industry. Furthermore, as shown in figure 7, industry, on the average, consumed only 2 percent of the water withdrawn. It is possible for industry and agriculture to work together in the West. Industry can purchase needed water rights with a small investment in lands to which the right belongs. (In Arizona the water must be used on the land.)

A trend to much greater interest in outdoor life may eventually have a great effect on our management of water resources. A rapidly growing segment of the public spends leisure time in boating, water sports, fishing, and wildfowl hunting—all activities that require large public investments in facilities. The reservoirs and wetlands needed for recreation increase consumptive uses and create management problems not heretofore of much concern. Even in humid regions withdrawals for filling reservoirs and wetlands may cause water-supply problems in small drainage basins. For example, in the Ohio River region an artificial marsh planted with mixed bulrushes, cattails, smartweed, and grasses may consume, through evapotranspiration, 41 inches of water

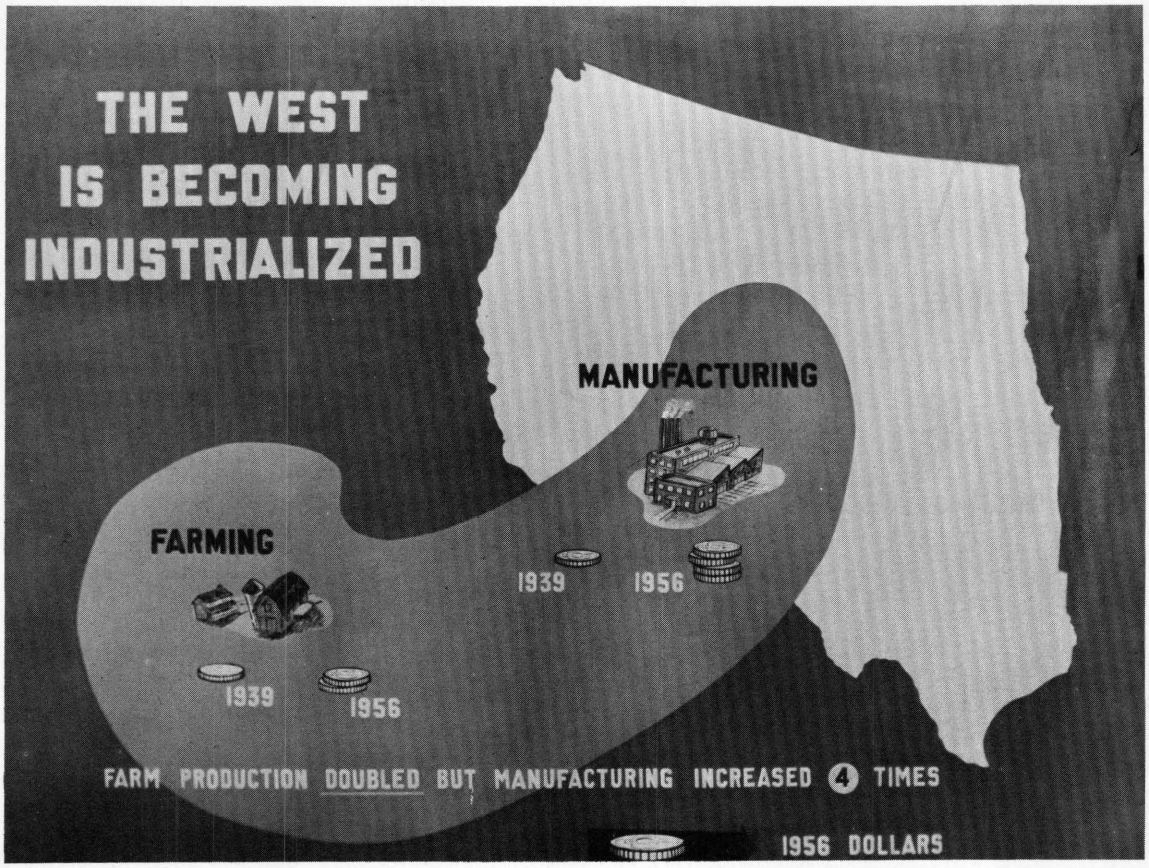

Figure 41

per year compared with 25 inches consumed by vegetation existing before construction. The 16-inch increase in consumptive use is a large withdrawal for a small drainage area. The average annual runoff in the Ohio region is only 16 inches. Recreation ponds built in the West will consume much larger quantities of water.

Several cities (New York, Los Angeles, San Francisco) have built costly aqueducts to carry water from the supply to the demand. One might question the reasoning that led to construction of some elaborate distribution systems when untapped supplies exist adjacent to the area of demand. In some cases better management of available supplies might have obviated the need for the costly aqueduct. If costs of desalting sea water become low enough, many major coastal areas will find supplies from long aqueducts are not competitive in price.

Future flood problems may be solved in several ways. Because floods are natural, man may cooperate with nature—outlaw further use of flood plains for industry and residence and let agriculture gamble on escaping damage from floods. One solution—and this appears most practicable—lies in flood plain zoning. Some urban areas subject to infrequent flooding would be open for industry—others, more frequently flooded, would be made into recreational areas. A second solution lies in flood insurance. The premium rates depend on the flood hazard so a man may insure his risk in occupying the flood plain if he can afford the insurance. The Federal Government will continue construction of flood protection works that can be justified. Many reservoirs built primarily for flood control will be designed to serve other purposes such as water supply and recreation. Reservoirs built for water supply and hydroelectric power will provide some flood protection.

The quality of present municipal water supplies is generally excellent. In only a few regions does the quality of public supplies ever become lower than standards set by the U.S. Public Health Service. Table 10 shows the very small percentage of U.S. population that is furnished public supplies that do not meet standards. Iron, sulfate, and dissolved solids are the water properties of most concern to the public. Table 11 shows that the quality of western public supplies is generally inferior to those of the East. As water demand increases, some western cities may be forced to use increasingly inferior supplies. Dallas, Tex., had to do this during the drought of the fifties.

Removal of salts from saline water is now practical as demonstrated at Coalinga, Calif., which uses a saline well as the raw water source. Considering the small quantities of salt to be removed (about 8½ pounds per million gallons of raw water with 1,000 parts per million concentration of salt) to make pure water, the use of ion exchange apparatus for desalinization of poor inland waters appears more feasible than of sea water (about 30,000 parts per million). When the concentration of dissolved solids in a stream that is the sole source of supply becomes too high, the city concerned may, in the future, resort to desalinization.

TABLE 10.—*Population served water not meeting drinking water standards for certain properties* [1]

Property	Maximum permissible concentration [2] (parts per million)	Percentage of population
Iron	0.3	5.4
Magnesium	125.0	0
Sulfate	250.0	2.2
Chloride	250.0	.7
Fluoride	1.5	.8
Dissolved solids [3]	500.0	5.2
Do.[3]	1,000.0	.7

[1] Based on 1952 inventory of 1,157 supplies representing more than 90 percent of the urban population.
[2] U.S. Public Health Service, 1946 drinking water standards.
[3] Dissolved solids concentration of less than 500 parts per million is recommended but 1,000 parts per million if no better supply is available.

TABLE 11.—*Maximum concentrations of chemical properties in public supplies of the United States* [1]

[In parts per million]

Property	75 percent of population		95 percent of population	
	East [2]	West [3]	East	West
Iron	0.16	0.13	0.36	0.29
Sodium	10	60	30	160
Bicarbonate	100	170	240	300
Sulfate	70	100	120	240
Chloride	20	50	50	100
Nitrate	3	5	6	10
Fluoride	.5	.7	.7	1
Dissolved solids	160	380	360	680
pH (units)	8.1	8.7	8.9	9.3

[1] Based on 1952 inventory of 1,157 supplies representing more than 90 per cent of the urban population.
[2] States east of the Mississippi River.
[3] States west of the Mississippi River.

Treatment of water supplies and wastes is expensive. Figure 42 shows that the annual cost of treating municipal and industrial supplies and wastes is about $1 billion now and may exceed $3 billion by 1980. The projections in figure 42 should not be confused with estimates of what it will cost to "alleviate pollution" or reach a certain water-quality condition in a specific location or in the United States. The projections are based on a gradual increase in percent treatment of wastes but never reaching 100 percent. Complete treatment of wastes so that the effluent has no

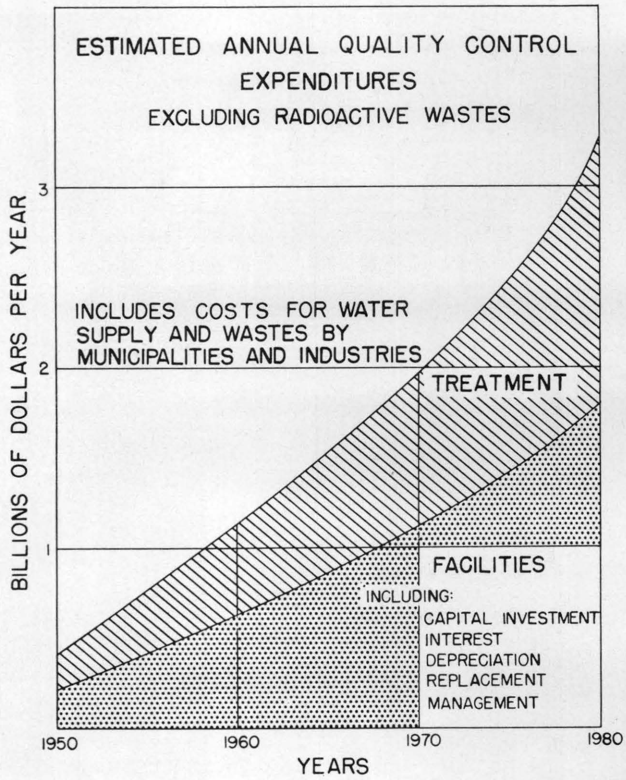

FIGURE 42

biochemical oxygen demand may become a legal requirement in some regions. Such a requirement will increase waste treatment costs. One solution for disposal of industrial wastes is pondage at the plant for release during periods of high streamflow when there is water available for dilution. The quality picture is one of steadily increasing costs as population and water use grow.

SUMMARY

Briefly summarized, almost every part of the United States faces current or potential water problems. Six major kinds of problems must be solved—supply, variability, distribution, floods, quality, and pollution. A supply problem exists when regional demand exceeds long-term regional supply. Variability problems arise when demand exceeds supply for short periods but supply—over long periods—is adequate to meet demand. Distribution problems are identified by great distance between the locations of supply and demand. Floods are an overabundance of streamflow—momentarily more than low-water channels can carry. Chemical-sediment problems arise from the natural leaching of weathering products—man may be guilty of speeding up the process. Pollution is predominantly man's fault—using streams for waste disposal deteriorates the water quality.

Supply is a problem in the Southwest. The potential water demand exceeds the long-term supply. Streamflow has been developed to near ultimate capacity. Withdrawals from ground water exceed recharge and water is being mined.

Variability is most severe in the streamflow of the Great Plains and Southwest. Much reservoir storage has been built in the region to partly solve the variability problem but because of long period variations in supply, more storage is needed.

Distribution problems are severe in the West where major streams are few and far between. Costly canals and pipelines carry water from diversion points to area of use.

Floods are a problem in all of the United States except part of the Southwest. They are a severe problem in New England, along the Atlantic coast from Washington, D.C., to New England, in the Ohio River region, Missouri River region, Columbia River region, and lower Mississippi region.

Chemical and sediment problems are troublesome in the Great Plains, Southwest, Great Basin, a narrow strip paralleling the lower Mississippi River, and in the Piedmont area of the Carolinas, Virginia, and Maryland. Encroachment of salt water into aquifers is a constant threat along the entire seacoast.

Pollution is a problem wherever industry and population are concentrated.

These are water problems of the United States. They can be solved but some solutions may be costly. Water is so inexpensive in the United States that the probable much higher water costs of the future will cause public concern.

Average annual runoff to the ocean of 8 inches bears witness to the overall abundance of water supply in the United States. In regions where supply fails to meet potential demand it is because the natural supply is poorly distributed by season or by location. Nationwide damages from floods continue to be high although much has been done to provide flood protection. Problems caused by chemical sediment characteristics and by pollution interfere with the optimum use of water supplies in some regions. The major water problems—supply, variability, distribution, chemical sediment, floods, and pollution—can all be solved at a cost. Sound management of the Nation's water resources is basically a problem in economics.

The current national water use is about 250 billion gallons per day—by 1980 it is estimated as about 600 billion gallons per day. The manageable supply of water available is 1,160 billion gallons per day. Only a part of the water used is consumed—most public and industrial supplies are returned to streams after use and, except for changes in quality, may be reused. Irrigation takes 46 percent of the present national use, and 60 percent of this is consumed. At present, industry uses an amount equal to irrigation but only 2 percent of the water is consumed. With 94 percent of industrial water used for cooling, the quality of industrial supplies is normally not as critical as for irrigation use.

Current shortages of water supply can be remedied in several ways if the water user can afford the cost. Water wasted by evaporation from reservoir surfaces or by transpiration from phreatophytes can be partially saved through better management of storage, treatment of reservoir surfaces, and eradication of nonbeneficial plants. In some water-short areas substitution of aquifer storage for surface reservoir storage would save much water. Importation of water from areas with surplus supplies may be the answer for some areas with deficient supplies. Demands properly matched with supplies—such as use of saline waters for cooling—may make supplies available for greater overall use. Desalinization of poor quality water may eventually be economical.

Changes in agricultural and industrial technology between now and 1980 may greatly affect the water situation. Irrigation may compete with industry for water in the humid East. Water for industry may be recirculated many times and water cooling may be supplanted by air cooling. High quality of surface supplies may be maintained by storing industrial wastes until floodflows are available for adequate dilution. All municipal wastes may be given 100 percent treatment. Recreational uses of water may seriously affect the supply in some areas. Reservoirs will be built not for a single purpose but for several purposes. More use will be made of groundwater supplies by skillfully managed recharge and withdrawals.

In the future the Nation must manage its water resources more skillfully than it has in the past. Economic factors will dictate much of the new water resource development. Before a water project is approved, all possible alternatives will be investigated and the final project will be the most economical of them. The Nation must give economic considerations the major part in future water management decisions or the economy of the country will suffer. The United States has adequate water if it is properly managed.

APPENDIX

TABLE 1.—*Water supply for water resource regions of the United States*

Region	Area (thousand square miles)	Average supply (cubic feet per second)	Supply available without storage for indicated time and storage required to make flow available 100 percent of time									
			95 percent		90 percent		80 percent		70 percent		50 percent	
			Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)
New England	59	104,000	9,800	1,300,000	15,000	1,900,000	24,000	4,200,000	34,000	7,300,000	61,000	26,000,000
Delaware and Hudson	31	49,000	5,000	590,000	7,400	900,000	12,000	2,000,000	17,000	3,800,000	29,000	11,000,000
Chesapeake Bay	57	79,800	8,700	960,000	13,000	1,400,000	20,000	3,400,000	28,000	6,000,000	49,000	20,000,000
Southeast	279	328,000	32,000	4,900,000	48,000	7,800,000	76,000	14,000,000	110,000	25,000,000	195,000	78,000,000
Western Great Lakes	81	65,700	13,000	780,000	18,000	1,100,000	25,000	2,800,000	32,000	5,100,000	49,000	20,000,000
Eastern Great Lakes	47	62,400	3,600	720,000	5,700	1,100,000	10,000	2,200,000	15,000	3,700,000	30,000	11,000,000
Ohio River	145	171,000	11,500	4,100,000	14,500	5,200,000	22,000	7,200,000	32,000	11,000,000	71,000	29,000,000
Cumberland River	18	26,000	2,300	160,000	3,300	288,000	5,100	620,000	7,000	1,100,000	12,000	3,100,000
Tennessee River	41	66,500	14,000	400,000	17,000	600,000	23,000	1,200,000	29,000	2,500,000	44,000	9,600,000
Upper Mississippi River	182	96,600	12,000	1,100,000	18,000	2,300,000	28,000	5,200,000	38,000	8,700,000	63,000	26,000,000
Upper Missouri River	518	28,700	1,800	340,000	2,800	660,000	4,900	1,200,000	7,000	2,100,000	14,000	5,700,000
Lower Missouri River	62	35,800	640	660,000	850	840,000	1,900	1,300,000	3,400	2,300,000	9,000	5,200,000
Upper Arkansas-Red Rivers	153	17,000	640	250,000	1,080	410,000	2,000	72,000	3,300	1,200,000	7,000	3,300,000
Lower Arkansas, Red and White Rivers	117	119,000	1,600	1,400,000	3,200	2,500,000	6,800	5,000,000	13,000	9,400,000	31,000	22,000,000
Lower Mississippi River	64	75,500	3,200	900,000	5,500	1,800,000	10,000	3,200,000	16,000	5,500,000	33,000	14,000,000
Upper Rio Grande and Pecos Rivers	136	(1)										
Western Gulf	205	71,300	1,400	1,300,000	2,600	1,700,000	5,300	3,800,000	9,100	5,500,000	22,000	12,000,000
Colorado River	258	4,900	330	90,000	490	120,000	870	230,000	1,300	380,000	2,600	1,200,000
Great Basin	200	5,800	470	72,000	720	100,000	1,200	240,000	1,800	420,000	3,300	1,000,000
South Pacific	13	550	40	10,000	60	13,000	100	26,000	150	43,000	280	119,000
Central Pacific	99	74,000	1,600	880,000	2,900	1,800,000	5,900	3,100,000	9,800	5,300,000	24,000	11,000,000
Pacific Northwest	257	222,000	15,000	2,600,000	33,000	6,650,000	41,000	9,300,000	61,000	16,000,000	117,000	47,000,000

[1] Appropriations currently exceed supply.

TABLE 2.—*Water supply for selected metropolitan areas of the United States*

Metropolitan area	Average supply (cubic feet per second)	Supply available without storage for indicated time and storage required to make flow available 100 percent of time										Source of supply
		95 percent		90 percent		80 percent		70 percent		50 percent		
		Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)	Flow (cubic feet per second)	Storage (acre-feet)	
Boston	7,980	1,280	72,000	1,900	160,000	2,620	290,000	3,480	600,000	5,380	2,000,000	Merrimac, Neponset, Ware, Parker, Ipswich, Aberjana, Mystic Lake, Charles. (No further supply assumed available from Swift.)
Hartford	17,300	3,160	186,000	4,200	342,000	5,850	810,000	7,510	1,440,000	11,500	4,260,000	Connecticut, Scantic, Hockanum, Farmington, Park.
New York	22,000	3,480	290,000	4,620	470,000	6,580	980,000	8,540	1,750,000	13,000	4,200,000	Hudson, Poesten Kill, Kinderhook Creek, Catskill Creek, Esopus Creek, Rondout Creek, Wallkill, Wappinger Creek, Fishkill Creek, Saw Mill.
Philadelphia	16,000	2,770	320,000	3,390	460,000	4,620	800,000	6,020	1,400,000	10,700	4,700,000	Delaware, Schuykill, Neshaminy Creek.
Albany-Schnectady-Troy.	14,400	3,110	250,000	3,810	320,000	5,010	550,000	6,420	1,000,000	9,030	2,400,000	Hudson, Poesten Kill.
Detroit	177,000	(1)	--------	--------	--------	--------	--------	--------	--------	--------	--------	Lake St. Clair, Detroit, River.
Washington	11,500	1,700	240,000	2,400	400,000	3,810	1,200,000	5,440	2,200,000	9,420	7,000,000	Potomac, Anacostia, Fourmile Run.
Richmond	7,440	1,100	90,000	1,500	100,000	2,100	220,000	2,800	420,000	4,600	1,500,000	James.
Chicago	(2)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	Lake Michigan.
Lansing	863	128	19,000	180	31,000	270	62,000	375	100,000	620	340,000	Grand.
Cincinnati	100,000	11,000	2,100,000	14,000	2,900,000	22,000	5,400,000	32,000	9,300,000	61,000	30,000,000	Ohio.
Indianapolis	1,624	172	36,000	203	45,000	257	60,000	361	92,000	629	193,000	White, Eagle Creek.
Nashville	20,000	3,000	150,000	4,100	330,000	5,900	700,000	7,800	1,300,000	12,000	3,300,000	Cumberland.
Chattanooga	37,400	20,000	120,000	22,000	170,000	24,000	280,000	26,000	440,000	30,000	800,000	Tennessee.
Birmingham	7,020	277	260,000	472	380,000	876	640,000	1,400	800,000	2,910	1,700,000	Black Warrior, Cahaba, Shades Creek.
Columbia	8,410	3,500	30,000	4,100	80,000	5,000	200,000	5,800	350,000	7,500	1,500,000	Broad, Saluda.
Cedar Rapids	3,090	440	45,000	600	84,000	880	150,000	1,200	260,000	2,000	670,000	Cedar.
St. Louis	180,000	61,000	2,000,000	76,000	5,000,000	97,000	10,500,000	118,000	17,000,000	155,000	33,000,000	Mississippi.
New Orleans	647,000	220,000	14,000,000	270,000	24,000,000	350,000	48,000,000	420,000	106,000,000	560,000	174,000,000	Mississippi (above Atchafalaya).
Denver	(3)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	
Sioux City	33,200	[4] 7,000	1,000,000	9,000	1,700,000	12,000	2,600,000	15,000	4,400,000	22,500	9,000,000	Missouri.
Kansas City	56,000	[4] 14,000	1,700,000	18,000	3,000,000	25,000	6,000,000	32,000	10,000,000	47,000	28,000,000	Do.
Little Rock	41,000	5,000	1,200,000	7,200	2,100,000	11,000	3,600,000	16,000	6,200,000	26,000	12,600,000	Arkansas.
Oklahoma City	375	(5)	--------	--------	--------	--------	--------	--------	--------	--------	--------	North Canadian.
Amarillo	472	1.5	4,000	3.4	7,000	9.0	14,000	19	24,000	60	55,000	Canadian, Palo Duro Creek.
Houston	2,500	(6)	--------	--------	--------	--------	--------	--------	--------	840	450,000	San Jacinto, Buffalo, White Oak and Brays Bayous.
Dallas	1,360	(7)	--------	--------	--------	--------	--------	--------	--------	--------	--------	Trinity.
Fort Worth	410	(8)	--------	--------	--------	--------	--------	--------	--------	--------	--------	West Fork Trinity.
San Antonio	160	70	400	80	800	95	1,900	110	4,000	130	9,000	San Antonio, Medina.
Albuquerque	1,040	[9] 115	7,500	160	13,800	240	30,000	315	50,000	500	125,000	Rio Grande.
Phoenix	1,530	(10)	--------	--------	--------	--------	--------	--------	--------	--------	--------	Salt, Verde.
Grand Junction	[11] 6,960	1,670	230,000	2,000	310,000	2,400	450,000	2,700	560,000	3,400	900,000	Colorado.
Portland	[12] 749	92	6,000	130	11,000	205	26,000	280	50,000	470	150,000	Bull Run.
Spokane	6,830	750	(13)	900	--------	1,350	--------	2,000	--------	3,700	--------	Spokane.
Salt Lake City	[14] 178	28	1,900	39	3,800	57	8,500	76	15,000	122	48,000	Big Cottonwood Creek, Little Cottonwood Creek, Parlays Creek, City Creek, Emigration Creek.
San Francisco	[15] 1,700	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	Local streams and wells, 4 major imports.
Los Angeles [16]	[17] 1,100	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	Local streams and wells, Owens-Mono Basin, Colorado River.

[1] Average monthly flow of Detroit River ranged from 100,000 cubic feet per second to 219,000 cubic feet per second for period 1936–51. No storage believed necessary.

[2] Chicago supply for municipal use is taken from Lake Michigan and is unlimited by decrees. The amount of flow released to the Chicago Sanitary and Ship Canal is controlled by a 1930 decree of the U.S. Supreme Court. The original ruling set a limit of not to exceed 1,500 cubic feet per second (which does not include domestic pumpage). The limit has been raised, at least temporarily, a few times since 1930. The net result of the legal controls is a limitation on industrial water use and none on domestic use.

[3] Denver supply presently withdrawn from South Platte River Basin, Williams River (Colorado Basin), and Fraser River (Colorado Basin). The supply is complicated by irrigation and storage rights. Some of the city rights are senior—some junior to other rights. The presently used water rights held by Denver are:

	Cubic feet per second
South Platte Basin	250
Moffat tunnel (transmountain diversion from Williams and Fraser, conditional decree)	1,280

The present yearly supply taken by Denver is:

	Acre-feet
South Platte Basin	86,000
Moffat tunnel diversion	93,000
Total (about 250 cubic feet per second)	179,000

Denver is constructing Roberts tunnel to bring water from the Blue River (Colorado Basin) to South Platte River. The decree will allow importation of 150,000 acre-feet per year via Roberts tunnel. Capacity of Moffat tunnel is 1,280 cubic feet per second. According to the U.S. Bureau of Reclamation (Colorado River, 1946) the potential export diversions from Eagle River, Piney Creek, Blue River, and Williams River to South Platte River are 500,000 acre-feet per year (equivalent flow 690 cubic feet per second). These export diversions are exclusive of the Denver transmountain diversions of 52 cubic feet per second (average 1937–57) via Moffat tunnel.

The total potential supply of Denver is estimated at 940 cubic feet per second.

[4] The operation plan for Missouri River reservoirs provides that during the winter months discharge at Kansas City will not be below 7,600 cubic feet per second. For an interim period this has been increased to 9,600 cubic feet per second. During the navigation season (June through September) flow at Kansas City will not be less than 12,700 cubic feet per second.

[5] Canton Reservoir, completed on North Canadian River in 1948, is partly used to provide dependable flows. Lake Overholser on North Canadian River built for Oklahoma City water supply began storage in 1917. Total usable capacity of Canton and Lake Overholser is about 120,000 acre-feet. Reservoir capacity, if used entirely for water supply, could provide a year-round dependable supply in excess of 150 cubic feet per second. Oklahoma City plans to import water from the eastern part of the State to supplement the supply from North Canadian River.

TABLE 2.—*Water supply for selected metropolitan areas of the United States*—Continued

[6] Lake Houston completed on San Jacinto River in 1954 for purpose of water supply. Usable reservoir contents (150,000 acre-feet) are sufficient to furnish at least 400 cubic feet per second dependable year-round flow based on the flow of San Jacinto near Huffman 1936–52.

[7] Present constructed storage above Dallas on various forks of Trinity River is as follows:

Stream	Reservoir	Capacity used for water supply regulation
West Fork Trinity	Bridgeport	270, 000
Do	Eagle Mountain	183, 000
Clear Fork Trinity	Benbrook	88, 000
Denton Creek	Grapevine	188, 000
Elm Fork Trinity	Lake Dallas	157, 000
Do	Garza-Little Elm	482, 000

If this storage is appropriately used it can make the average flow dependable throughout the year.

[8] Present storage capacity above Fort Worth, if effectively used would provide dependable flow of 300 cubic feet per second.

[9] All of present Albuquerque supply taken from wells. State engineer has ruled that additional wells can be drilled and pumped only if the city buys an equivalent surface-water right offsetting the water depleted by the wells. The present supply in the Rio Grande is wholly appropriated and much of the flow at Albuquerque is the property of Texas and Mexico under compact or treaty provisions. If the legal barriers (in compacts and treaties) can be satisfied and water rights purchased the quantities of water shown may be developed through storage. The San Juan-Chama project (under consideration) will bring about 45,000 acre-feet of water annually from a transbasin diversion to supplement the flow of Rio Grande being withdrawn by Albuquerque.

[10] Phoenix is situated at confluence of Verde and Salt Rivers. Long-term average flow of Salt River below Verde River (obtained by adding flows below Bartlett Dam and Stewart Mountain Dam) is 1,530 cubic feet per second. Storage completely developed on Salt River. Capacities of Reservoirs on Verde River are 322,300 acre-feet which will provide year round flow of 600 cubic feet per second. However, flows are all appropriated and city could obtain needed water only by purchase of water rights.

[11] Average supply in Colorado River. Withdrawals would necessarily compete with prior water rights. Supplies and associated storage computed without regard to water rights.

[12] All of present Portland supply taken solely from Bull Run River. Ben Morrow Reservoir with total capacity of 30,140 acre-feet can furnish dependable flow for 100 percent of time of about 220 cubic feet per second. Tremendous supplies available in Columbia River if present source ever proves inadequate.

[13] Spokane supply presently taken from wells. Spokane River could be used as source of supply. No storage has been listed as flow under present regulation is believed adequate for long range requirements.

[14] Present Salt Lake City supply withdrawn from 5 creeks and some artesian wells. About 90 percent of the total is taken from the creeks and about 10 percent from the wells. Some storage already built on Big Cottonwood and Parleys Creeks. Additional supplies are available from Provo River where water is stored in Deer Creek Reservoir.

[15] Total supply available locally in the San Francisco area and by import through Hetch Hetchy aqueduct, Mokelumne aqueduct, Contra Costa canal and from Cache Slough.

The local supply is completely used.

Present Hetch Hetchy aqueduct capacity is about 250 cubic feet per second. By construction of additional storage, pipelines and an additional tunnel through the Coast Range the capacity can be increased to about 620 cubic feet per second.

Mokelumne aqueducts (No. 1 is 65 inches in diameter, No. 2 is 67 inches) presently have a capacity of about 240 cubic feet per second. Additional storage, more pumps, and a 3d pipeline will increase the capacity of the aqueducts to about 310 cubic feet per second which is about the limit of development of the Mokelumne River.

The Contra Costa canal brings water from Sacramento and San Joaquin Rivers to the San Francisco Bay area. It has a capacity at the delivery end of 269 cubic feet per second (Martinez Reservoir).

The Cache Slough diversion system brings water from Cache Slough to Vallejo. The cpacity is about 35 cubic feet per second.

[16] Los Angeles metropolitan area of about 4,500 square miles is bounded by Pacific Ocean and crests of San Gabriel, San Bernardino, and San Jacinto Mountains.

[17] Estimated net annual average water supply available from streams within the metropolitan area is 1,100 cubic feet per second. The local supply is fully used now. Imports of water are made from Owens and Mono Basins and from Colorado River. The capacity of Owens River aqueduct is 480 cubic feet per second and it has been used to full capacity since 1943. Imports from Colorado River through the Colorado River aqueduct for the Metropolitan Water District of Southern California (San Diego County in addition to Los Angeles metropolitan area) have steadily increased since the start in 1941. In 1957 Colorado imports were equivalent to about 550 cubic feet per second. The ultimate capacity of the Colorado aqueduct is 1,600 cubic feet per second of which about 1,500 cubic feet per second is reserved for the Los Angeles metropolitan area. The water right for the Colorado aqueduct is in litigation before the U.S. Supreme Court. The Feather River project when complete will deliver about a maximum of 2,500 cubic feet per second to southern California.

The sum of present supplies available locally and by importation is about 3,000 cubic feet per second. The U.S. Supreme Court decision in the Colorado River case will greatly affect the ultimate supply available to Los Angeles.

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