GEOLOGICAL SURVEY CIRCULAR 114

June 1951

THE WATER SITUATION IN THE UNITED STATES WITH SPECIAL REFERENCE TO GROUND WATER

By

C. L. McGuinness

With a Summary of the Current Water Situation by States
Based on Data Supplied by Field Offices
of the
Water Resources Division

Adapted from a Report Prepared for the President's
Water Resources Policy Commission

UNITED STATES DEPARTMENT OF THE INTERIOR
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Washington, D. C.

Free on application to the Geological Survey, Washington 25, D. C.

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INTRODUCTION

This report constitutes appendixes B and C of a report prepared in April 1950 by the Geological Survey at the request of the President's Water Resources Policy Commission. The full report was entitled "Water facts in relation to a national water-resources policy." The brief text, entitled "Water in relation to the national economy," and appendix A, entitled "A summary of the water situation in the United States, with special reference to ground water," were drafted by A. M. Piper of the Geological Survey and are to be published separately, in slightly modified form, under his name.

This report discusses the occurrence of ground water in nature and its relation to surface water and to the national water picture as a whole, and it lists numerous existing water problems and discusses their solution.

The report would not be complete without acknowledgment of the part played by agencies other than the Geological Survey in gathering the data on which the report is based. These include especially the cooperating State, county, and local agencies that form an indispensable part of the Federal-State team of water-resources investigators. Included also are State agencies with which formal cooperation is not in effect or has begun only recently, but which furnished a large part of the data on ground water in such States as Illinois and California. Other Federal agencies, especially the Bureau of Reclamation, the Army Engineers, and bureaus of the Agriculture Department, furnished a large amount of the data used in the report. Consulting firms

and contractors engaged in water-project design and construction, including many well drillers, work closely with the Geological Survey and regularly furnish data essential to the studies of the Survey, as do many waterworks operators and private water users. Such data were used freely in the preparation of this report. To all these agencies and individuals the Geological Survey expresses deep appreciation, and regret that limitations of space and time did not permit mentioning them all by name; specific mention of a few is not intended to indicate that they contributed more than others not named.

In order to save the time and expense required to set up the report in the usual style for Geological Survey circulars, it is reproduced here from the same negatives and plates used in duplicating copies for the Water Resources Policy Commission. A few minor typographical errors remain, but they do not seriously affect the meaning of the sections of the report concerned.

Most of the illustrations were adapted from published reports or previously drafted exhibit material. They were prepared or selected by a committee consisting of W. P. Cross, C. M. Roberts, and G. G. Parker, and were drafted by Ross A. Ellwood and Rodney Hart. Figure 17 was compiled by H. E. Thomas for his report to the Conservation Foundation (see p. 97).

Mr. Cross drafted the summary of cost analysis on pages 82 and 83. W. W. Hastings drafted the statement on quality-of-water studies on page 125. W. B. Langbein drafted the statement on public lands on pages 129-130. A. M. Piper drafted the list of basic-data needs on pages 126-127 and the list of principles on pages 133-134.

GROUND WATER IN NATURE

The Hydrologic Cycle

Water is like a living thing. Essentially all of it that is usable is in motion--a part of the vast circulatory system known as the hydrologic cycle. In this cycle water evaporates wherever it is exposed to the air, but especially from the oceans; rises into the atmosphere; travels as a part of vast air masses over ocean and land; is condensed when an air mass rises to pass over another or over a mountain range; and falls as rain or snow. Much of it falls on the ocean. In some areas a substantial amount is condensed directly from the air onto the land as dew. Not all the rain and snow that falls reaches the earth--some of it evaporates in falling or falls on a tree or other plant and is evaporated from it, and so completes a cycle very quickly.

We begin to count our available water as it reaches the surface. That which reaches the surface may travel a straight and simple path or a tortuous and complicated one, but it all is destined to go back to the ocean, the primary reservoir.

Some of the water evaporates immediately; some of it penetrates the soil and is held there for a time (the amount depending on the kind of soil and its previous moisture content), later to be evaporated or transpired by thirsty vegetation; some of it falls directly on the river channels and thus contributes immediately to river discharge; some is shed by the ground and reaches the streams very promptly. If the rain continues, some of the water may pass below the reach of plant roots, a part reappearing as wet-weather springs or seeps, and a part going farther down into the unsaturated subsoil zone above the water table where water is held in the pores by capillary force as it is in the soil (fig. 2). This zone has its moisture-holding capacity too--equivalent in some areas to many inches of water--and if it has been partly dried out by slow evaporation during a long rainless period its moisture must be replenished. Finally, after the moisture demands of the soil and subsoil have been satisfied, at least in places if not throughout a whole area, if the rain still continues or if repeated rains occur there is an excess that can reach the water table. A drop enters at the top of the saturated soil and another drop is pushed out at the bottom; that drop enters one of the larger saturated capillary openings in the subsoil and pushes out another farther down, much like successive drops of rain on a dirty window pane form a little crooked rivulet, from the bottom of which a drop runs off whenever a new one is added at the top.

Finally some of the drops reach the water table--the top of the zone in which the openings in the rocks are fully saturated and in which the water can flow under the influence of gravity as it does in a river, though much more slowly. Just before reaching the water table the water becomes a part of and passes through the "capillary fringe"--the zone where water is held up above the water table by capillary force and where, though the capillary "threads" are connected to the water table, the water in them still will not flow into a well.

Now, the raindrops have become ground water, but only after submission to many prior claims. If the rain falls slowly over a long period the ground water may be replenished before any water runs off at the surface, but commonly the rainfall rate exceeds the infiltration capacity of the soil for a time while the subsurface demands are still unsatisfied, and water is rejected and runs off at the surface. In cold climates there may be much rejection of this kind

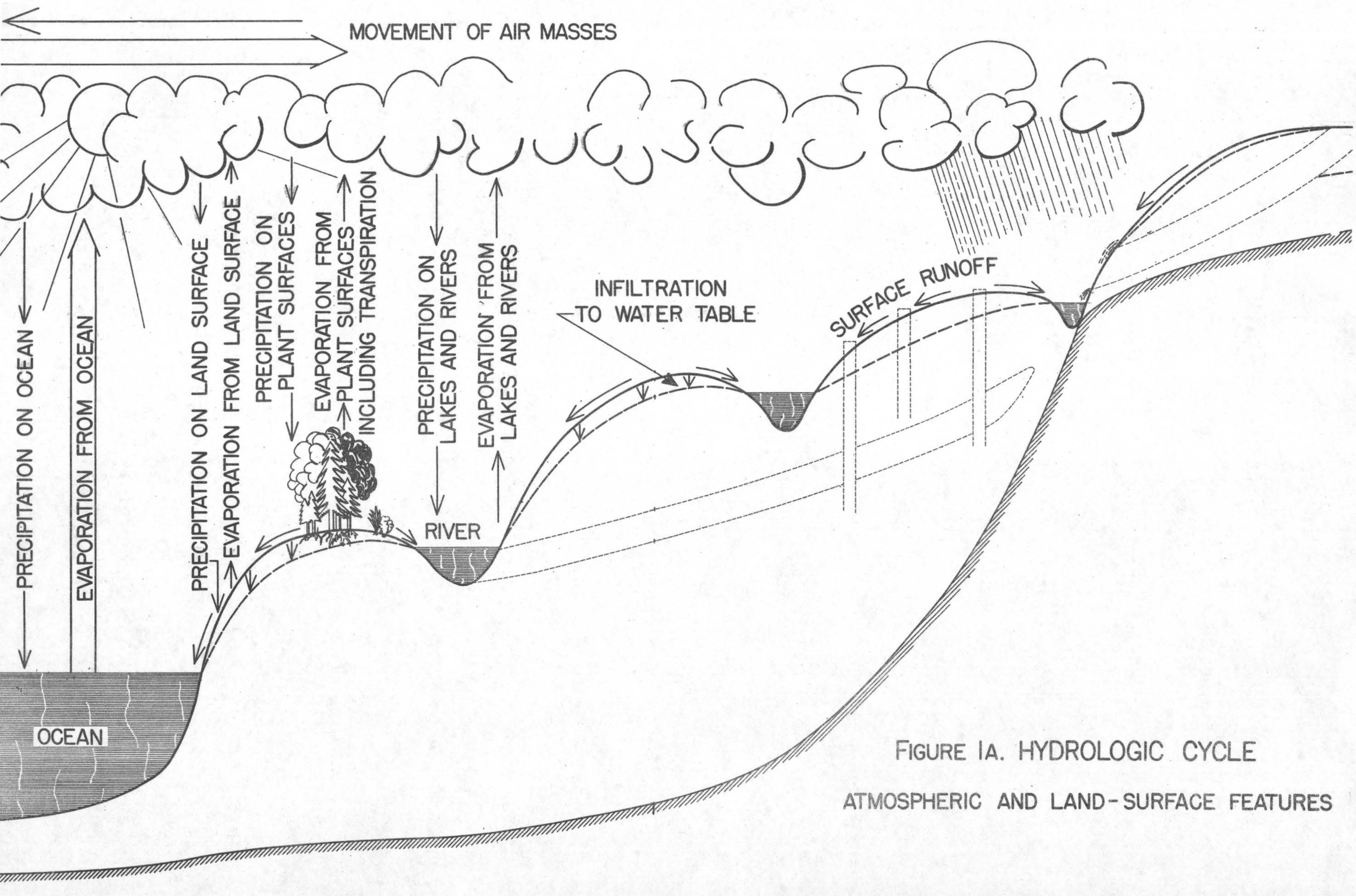


FIGURE IA. HYDROLOGIC CYCLE

ATMOSPHERIC AND LAND-SURFACE FEATURES

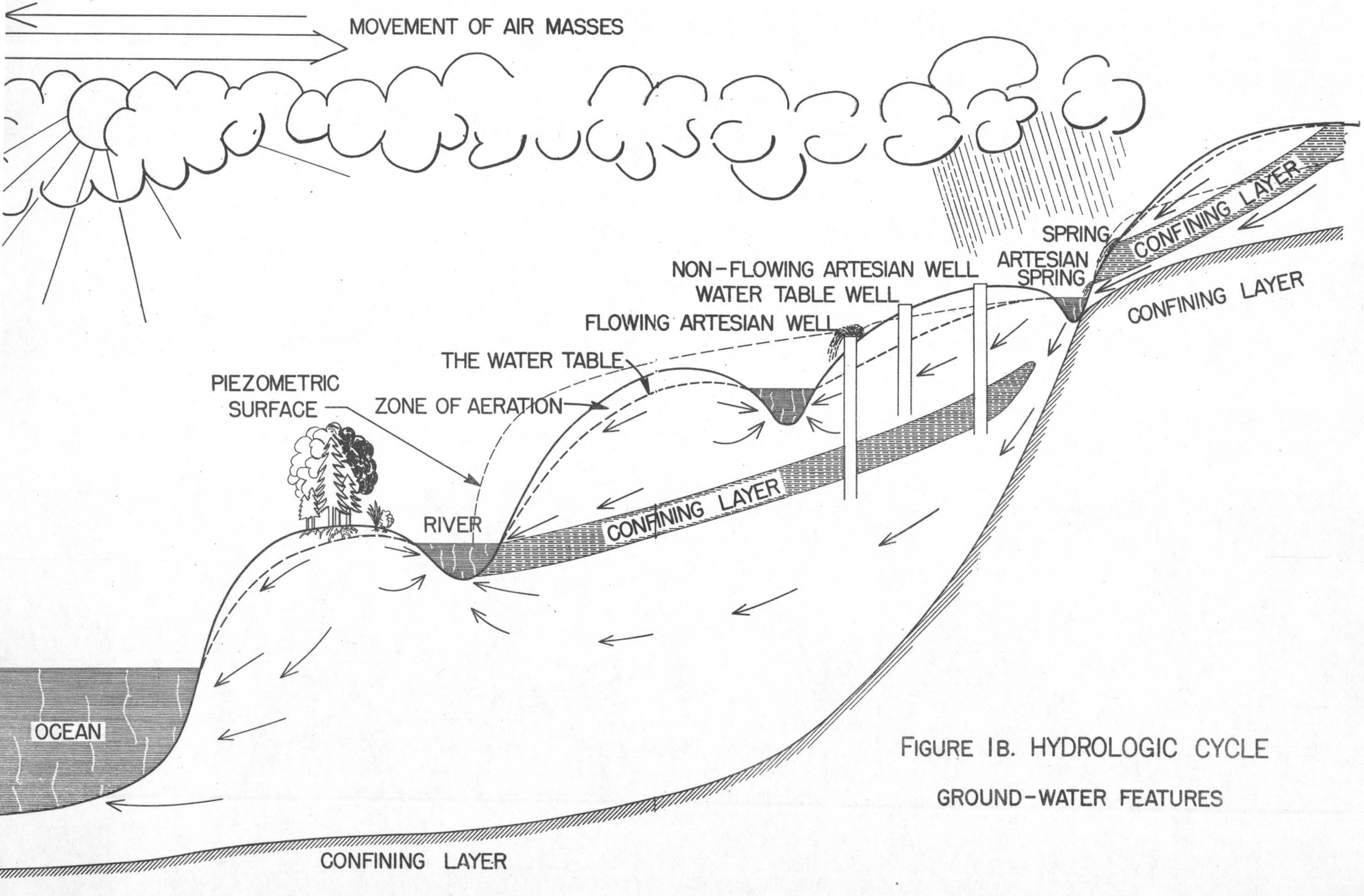


FIGURE 1B. HYDROLOGIC CYCLE

GROUND-WATER FEATURES

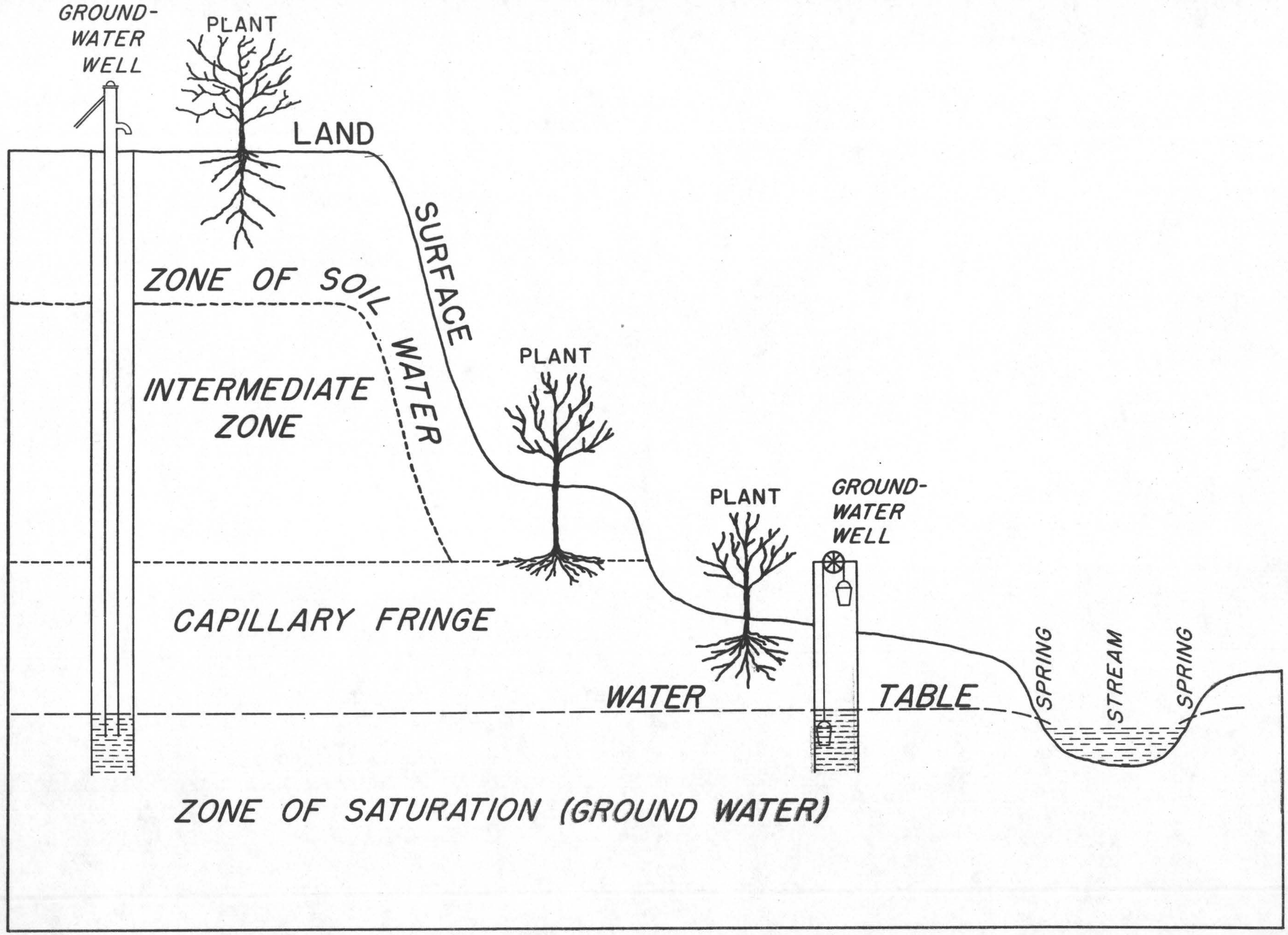


FIGURE 2. ZONES OF SUB-SURFACE WATER

because rains may fall while the soil is still frozen and tight. But, regardless of whether ground-water recharge or surface runoff predominates at a given time and place, on the whole they share the lowest priority on the water that falls from the sky.

The ground water flows slowly through the rocks--slowly because of the friction between the water particles and the sides of the small pores or cracks in the rocks. It moves, always under the influence of gravity, toward some lower area of natural or artificial discharge. Under natural conditions the discharge may be into a river through a spring, or simply by slow seepage that is not concentrated enough to be called a spring. Or it may be by evaporation or transpiration along the river's edge, or in a swamp, or in and near the bed of a dry salt lake in the West. A part of the liquid discharge is directly into the ocean rather than into streams; the amount is large in an absolute sense but it forms only a small fraction of the total ground-water discharge. By far the largest part of the total ground-water discharge is into streams in humid areas.

If the water enters a stream it still may not reach the ocean. The stream may be one that flows to the floor of an enclosed basin in the West-the dry salt lake of the last paragraph, there to be evaporated. Water is, of course, lost almost continuously from any stream by evaporation. Water may be taken from the stream and used by man, and returned in part or not at all. In the West particularly, the stream may leave a mountain gorge and seep into the sandy bottom of an alluvial valley, thence to flow underground to another stream or even to the lower part of the same stream, where it comes to the surface once more; or to flow to the dry or salt lake that represents the destination of both ground and surface water of the scores of enclosed basins of the West. Or it may flow to a well and be pumped out for irrigation, in part being discharged by evapo-transpiration and in part returning to the water table, to move underground to the same or another well or to its natural place of discharge.

The many ways in which water circulates are illustrated in figure 1, which depicts the hydrologic cycle in a generalized way.

This description of the principal parts of the hydrologic cycle—there are many important modifications, such as detention of water for a time in the form of snow and ice —serves to point out an all-important fact. Water is water—it is vapor at one time, rain, snow, or dew at another, surface or ground water at another. It may be surface water one moment and ground water the next, and vice versa. But it is all water, and it must be considered as a whole—each phase in relation to the others and to the entire hydrologic cycle. We cannot discuss ground water and forget the surface water that feeds it in some places and is fed by it in others. We cannot discuss either and forget the precipitation that forms the ultimate source of replenishment for both. If this report did nothing more than to bring out the necessity for an integrated approach to the whole water problem, it would have served its purpose. It cannot be emphasized too strongly that such integration is the primary requisite for an orderly and systematic investigation of our water resources.

Ground Water in the Hydrologic Cycle

The place of water-bearing formations in the hydrologic cycle is twofold. As functional elements of the natural drainage system, they transmit water from one place to another, sometimes for long distances, and they act as the Nation's greatest storage and regulating reservoirs. Our underground reservoirs have an enormous capacity to store surplus water in wet periods, by virtue of the fact that water entering them is prevented by friction from draining away as quickly as it would in streams. They have a similar capacity to pay out water slowly in rainless periods, sustaining the flow of streams in which all direct surface runoff has passed downstream after the last rain, and which, except for the ground-water discharge, would be dry. The usable storage capacity of our underground reservoirs cannot even be approximated on the basis of our present data. In the Sacramento Valley alone, the total storage capacity between depths of 20 and 200 feet is estimated at about 34 million acre-feet,_/ equivalent to something like one and a quarter times the usable

_/ Poland, J. F., and others, Ground-water storage capacity of the Sacramento Valley, Calif. U. S. Geol. Survey rept. prepared for publication by the California Div. Water Resources, November 1949.

capacity of Lake Mead. Not all this capacity is usable, but a large part of it is. The usable capacity in the Sacramento Valley is much larger than the average for ground-water reservoirs of comparable size in the Nation as a whole, but it shows that the total is tremendous--many times that in all man-made surface reservoirs, which in 1946 amounted to more than 160 million acre-feet._/

_/ Harbeck, G. E., Jr., Reservoirs in the United States: U. S. Geol. Survey Circ. 23, fig. 1, March 1948.

The Underground Reservoirs

The underground reservoirs or aquifers of the Nation are its rock formations_/

_/ Meinzer, O. E., The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489, 1923.

using the work "rock" to describe both consolidated formations and the unconsolidated sediments like gravel and sand. The foundation of the United States consists of dense rocks like granite known as "basement rocks." These rocks come to the surface in the hearts of our major mountain chains, in the Piedmont Plateau from New Jersey to Alabama, and in some other scattered areas. They lie beneath a covering of young glacial clay, sand, and gravel in New England and northern Wisconsin. Elsewhere they are covered by stratified rocks ranging in thickness from a few feet to many thousands of feet. The stratified rocks are consolidated sedimentary formations like limestone, sandstone, and shale, unconsolidated sediments such as gravel, sand, and clay, and volcanic rocks such as the great lava flows of the West.

The capacity of the rocks to absorb, store, and yield water depends on the abundance and the size and shape of openings in them. There is nearly an infinite range in size of the openings, from submicroscopic pores in clay and shale to huge tunnels in lava flows and caves in limestone. The openings are primary--such as pores in sand, gravel, and clay; or secondary--such as fissures in rocks that have been indurated and then cracked by earth movements.

The occurrence of water in rock formations depends not only on their own character but on their position with respect to the land surface, their structure--the way they dip or are folded or faulted, the way in which they alternate with non-water-bearing rocks, and the extent to which they are exposed to recharge and the extent to which water is available for recharge.

All but the tightest rocks--clay, soft shale, volcanic ash, or dense, unfractured hard rocks--will yield at least a little water where the other conditions mentioned above are such as to permit water to enter and move through the rocks. There are extreme variations, however, in the capacity of the different rocks to hold and to yield water. The most prolific water bearers are the cavernous limestones such as those which supply the huge limestone springs in Florida and Missouri and the lava rocks such as those which feed the springs along the Snake River in Idaho. _/ Far outweighing

_/ Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, 1927.

these in national importance, however, are the widespread and varied deposits of gravel and sand which yield the bulk of the ground water the country over. _/

_/ Meinzer, O. E., op. cit. (Water-Supply Paper 489), pp. 117-118, 1923.

Sandstones are less productive than sands because their pores are filled partly by cementing material; indeed, some important sandstone formations yield most of their water from cracks rather than pores. The least productive rocks that yield useful supplies are those in which the water occurs in small cracks rather than large pores or caverns. These include the bulk of the consolidated sedimentary rocks and the "basement rocks" as well. Such rocks, however, are very widespread and are generally capable of yielding the small supplies of water needed on the farm. Also, these rocks, and even those less productive ones that will yield a little water but not enough for a household well, serve an important purpose, for a rock formation that will yield only a little water to a well may serve as an important storage and regulating reservoir when its whole extent is considered.

The total storage capacity of the Nation's underground reservoirs is enormous. According to the available data, which are not adequate for more than the roughest of estimates, it is many times greater than the capacity of all the streams and lakes and reservoirs, excluding the Great Lakes. The parts of the Great Lakes within the United States hold enough water to cover the United States to a depth of more than 6 feet—many, many times the combined capacity of all other lakes, streams, and reservoirs—but the ground-water storage is thought to exceed even that great amount.

There is a most important difference between total storage and usable storage, however. Under natural conditions the ground-water reservoirs can fill up to a certain point at a given rate of input before their spill equals that rate. The higher the rate of replenishment the higher their level must rise before the discharge reaches an equal rate. When replenishment stops the reservoirs continue to drain out, at a gradually decreasing rate, until another period of replenishment occurs or until they drain down to the level of the streams that form their natural outlets. As a practical matter, however, complete draining seldom occurs, except from thin dissected deposits perched on hills of tight rock, like the smaller patches of the terrace deposits of orange-colored clayey gravel near Washington, D. C. Thus, the average usable storage capacity under natural conditions is represented by the "effective porosity" or drainable pore space in the zone between the average highest and lowest levels of the water table. Much water remains in storage below the lowest natural stage of the water table, however, and some of this storage can be utilized by pumping water from wells.

Also, usable storage capacity is less than total by the amount of water retained in the smaller openings by capillary attraction, against the pull of gravity. Thus, when a saturated rock is drained, films of water remain behind, coating the grains or lining the crevices. The smaller the openings, the larger the part of the water so held. In a clay, the pore space may amount to more than 50 percent of the total volume and may be filled with water, yet every bit of the water may be held against the pull of gravity so that it cannot flow into a well or stream. In a clean coarse gravel the porosity may be only 20 or 25 percent but the amount of water retained against gravity may be only a small fraction of this.

Finally, usable capacity is less than total where the stored water is of poor quality, as it is at depth in many aquifers. Here, economic considerations may come in because water useless for one purpose may be good for another, and in some places the poor water can be displaced by good water artificially recharged from the surface. However, the saline parts of many ground-water reservoirs are of little use either in the natural cycle or to man; indeed, they may complicate efforts to obtain fresh water by discharging small quantities of poor water in such a way as to spoil a fresh-water supply.

From the standpoint of usefulness for water supply, it might be well to consider the underground reservoirs as divided into two great classes, though it should be pointed out that there is no sharp line--indeed, a complete gradation--between them._/ The first are those with a high rate of recharge, transmission, and discharge, and which therefore are capable of yielding large perennial supplies. The second are those with a low rate of recharge and small perennial yield, where heavy withdrawals by man are largely from storage and cannot be continued indefinitely. Some of the second type have yielded large supplies of water over the years, however,

_/ McGuinness, C. L., Recharge and depletion of ground water supplies: Am. Soc. Civil Eng. Trans., Paper No. 2318, vol. 112, 1947, pp. 972-998.

and with proper management can continue to be useful both for water supply and as storage reservoirs. Examples of the first class are the limestones of Florida, the alluvium of some of the Western basins, and the productive glacial gravels of the Ohio Valley and the Pacific Northwest. Examples of the second class are the sands and gravels of the High Plains, known as the Ogallala formation, the Dakota sandstone of the Dakotas and States to the south, and the consolidated limestones, sandstones, and shales in the Middle West.

Water-Table and Artesian Conditions

Before going further into the part the ground-water reservoirs play in the national water picture, it would be well to take time to make the important distinction between water-table and artesian conditions. Under water-table conditions the top of the zone of saturation is a "free" water surface at atmospheric pressure, and the ground water behaves much like water in a surface reservoir, except that friction makes it move much more slowly. The zone of saturation extends downward to impermeable rocks that prevent the water from descending further toward the center of the earth. This depth varies from place to place but is generally many hundreds of feet; however, in many regions only the upper few hundred feet is of importance.

Under artesian conditions water becomes confined under pressure between two bodies of impermeable rock. It does so by entering the ground, reaching the water table, and then flowing down with the slope of the water table to a point where the zone of saturation is interrupted by an impermeable bed. Part of the water may pass above the bed and continue to flow under water-table conditions, and part of it flows beneath the bed. Now it is confined, pressing upward against the impermeable bed with a head equivalent to the difference in elevation between that point and the elevation of the water table in the area of recharge, less the loss in head resulting from friction in movement. This is confined or artesian water; it will rise in a tightly cased well to a height above the bottom of the confining bed equivalent to the pressure head at that point. If the head happens to be above the land surface, as it commonly is in the valleys or along the coast in areas characterized by artesian formations, the well will flow. (See fig. 1.)

Water-table and artesian aquifers differ markedly in their usable storage capacity. Artesian aquifers are comparable to systems of piping; they are full of water at all times, receiving water at the upper end of the system and discharging it at the lower. When water is withdrawn from such an aquifer at a given point, as through a well, the water is derived from storage by compaction of the aquifer and by the slight expansion of the water itself as the pressure is lowered, until the effect of the withdrawal extends back to the intake area and results in a lowering of the water table there and perhaps in an increase in the rate of recharge, or to the discharge area where it results in a reduction of natural discharge. When water is withdrawn from a water-table aquifer it comes from storage by actual draining of the free or "gravity" water from the pores; here again the withdrawal from storage continues until it is balanced by an increase in recharge or a decrease in natural discharge, or both. _/

_/ McGuinness, C. L., op. cit., p. 973.

The usable storage capacity of a water-table aquifer, called its specific yield,_/ is much larger than that of an artesian aquifer, called its

_/ Meinzer, O. E., Outline of ground water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, p. 28, 1923.

coefficient of storage._/ The specific yield of a water-table aquifer (the

_/ Theis, C. V., U. S. Geol. Survey, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., 1935, pp. 519-524.

fraction of a cubic foot of water that will drain out by gravity from a cubic foot of saturated rock) may range from 0.01 or 0.02 to more than 0.40 and commonly is 0.10 to 0.25._/ The coefficient of storage of an artesian aquifer

_/ For example, see Stearns, Norah D., Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596-F, pp. 164-169, 1928.

(the fraction of a cubic foot of water released from storage in a vertical column of the aquifer 1 foot square when the head is lowered 1 foot) may range from 0.00001, or even less, to 0.005, but seldom more—commonly 0.0001 to 0.001._/

_/ Unpublished data in files of U. S. Geol. Survey.

Water-table and artesian aquifers differ importantly in their reaction to withdrawal of water from wells. The water table of an unconfined aquifer and the piezometric surface of an artesian aquifer—the imaginary pressure surface showing the level to which water will rise in artesian wells—behave in exactly the same way when wells discharge, but in vastly different degree.

Because of the larger amount of water available from storage in an unconfined aquifer when the water table is lowered by pumping, the "cone of depression" caused by pumping spreads much more slowly than the analogous cone of depression in the piezometric surface of an artesian aquifer. Thus the unconfined or water-table aquifers have a much larger usable storage capacity than the artesian aquifers, and they function to a larger extent like surface reservoirs in that a large part of their stored water can be withdrawn between periods of replenishment. The artesian aquifers function more like conduits between recharge and discharge areas, and the effects of withdrawal reach the outcrop areas relatively soon, after which the rate of decline of the water level slows down as water is withdrawn from storage in the water-table part of the aquifer, and eventually the decline may stop if the lowering of the water table induces increased recharge or cuts down natural discharge. Nevertheless, the storage function of artesian aquifers is important, because until the effects of withdrawal reach the outcrop area all the water has to come from storage, and in extensive artesian aquifers like the Dakota sandstone or some of the sands of the Atlantic and Gulf Coasts many years may pass before the water levels are adjusted to the pumping and the withdrawal from storage and accompanying decline in water level cease.

Only water-table aquifers are accessible to recharge directly from above. Artesian aquifers are recharged by movement of water from areas where the upper confining bed is absent and water can enter from the surface or from an overlying aquifer. In general, water-table aquifers are those with the greatest recharge and yield and those most susceptible to artificial management.

Operation of the Ground-Water Reservoirs

Let us consider in a little more detail the operation of the ground-water reservoirs as a part of the natural water system. Water enters--recharges--a ground-water reservoir by one of several processes; moves through it under the influence of gravity, forming, while it is there, a part of the Nation's stored supply; and discharges from the reservoir, again by one of a number of different means. It should be pointed out that the water, if not used when available in the reservoirs, discharges from them and continues to move in the hydrologic cycle; it is not conserved at that place by simply failing to use it. The storage function of the aquifers has been touched upon already. The other phases of the ground-water part of the hydrologic cycle need similar explanation.

Recharge

Ground water is recharged principally by one of two processes--infiltration of water from precipitation and infiltration from surface-water bodies. The source of the water in both cases is precipitation. No important recharge of ground water occurs other than from precipitation--"meteoric water"--though in a few volcanic areas a little "juvenile" water is believed to be added from cooling igneous rocks, and there is much lively debate among geologists as to whether "juvenile water" added a little at a time throughout geologic ages is not the ultimate source of all our water. Also, there are a number of minor ways in which recharge can occur. A heavy dew could add enough water to a saturated soil to cause some recharge, though such an occurrence would be rare. Dew, however, does meet a part of the moisture demand of vegetation. Recharge may even occur by movement to the water table of water in the vapor stage. Such movement always occurs when the humidity of a body of air increases over that of an adjacent body--a "moisture gradient" is set up from the more humid to the drier air; a similar gradient is set up also from a warmer body to a cooler one, as the formation of dew itself shows. How important this type of ground-water recharge is we do not yet know--probably not very important where the depth to the water table is substantial--but research is needed to evaluate the process to determine its place in the hydrologic cycle.

Speaking very generally, it may be said that recharge from precipitation is the dominant process in the humid East, and recharge from stream flow in the arid West. In the humid areas there is enough precipitation, at least during part of the year, to satisfy in substantial degree the prior claims for evaporation and soil-moisture replenishment and still to yield an excess for ground-water recharge and surface runoff. In the arid areas the potential evaporation--the amount of water that the air could take away if it were available--so far exceeds the precipitation that only heavy rainstorms are able temporarily to overcome this deficiency and to provide water for ground-water recharge and surface runoff.

Recharge is a seasonal phenomenon in practically all parts of the country. There are parts of the year when, because of such things as greater-than-average precipitation, reduced demands for evaporation and plant use (transpiration) caused by cold weather, or release of water from snow and ice caused by warm weather, enough water is available to saturate the soil and reach the water table or run off. The season when this happens is not the same in one part of the country as in another, nor, indeed, in one part of the country every year, but in each major region there is a characteristic pattern.

In the humid Northeast, Midwest, and Northwest, recharge is predominantly a springtime phenomenon. Typically the water table is low as a result of winter-long drainage of ground water into the streams, without compensating recharge because the soil is frozen and tight and the available water is locked up as ice and snow, and so a maximum amount of usable storage space is available in the underground reservoirs. When warm weather comes, the frost in the soil and the overlying snow melt, the temperature is still not so high as to cause much evaporation, and the vegetation has not yet begun to use much water, and thus much water is available to saturate the soil and to recharge the ground water and fun off at the surface._/ Spring rains

_/ McGuinness, C. L., U. S. Geol. Survey, The importance of snow in relation to ground-water recharge: Central States Snow Conf. Proc., vol. 1, Lansing, Mich., pp. 166-172, December 1941. Prepared in cooperation with Michigan Geol. Survey Div.

add to the available water in most years. If the melting takes place too quickly, much surface runoff may occur before the soil is completely thawed and capable of transmitting water downward, and disastrous floods may result. Heavy rains occurring at the same time will add to the floods, as in the 1936 floods in the Northeast._/

_/ Grover, N. C., and others, Floods of March 1936: U. S. Geol. Survey Water-Supply Papers, 798, 799, and 800, 1937.

At any rate, in the humid areas ground-water recharge generally is greatest in the spring, and the amount of water stored, as shown by the water levels in wells, reaches a maximum. As spring gives way to summer, the rains may continue or even increase, but evaporation and transpiration increase even more rapidly and soon dispose of all or nearly all the rainfall; only exceptionally heavy rains are likely to produce substantial ground-water recharge in these areas during the summer. Thus, because ground water continues to drain out even though recharge is not occurring, the amount of stored water is diminished and the water table declines during the summer. In the fall it is generally at a low stage. If it then rains more than heavily enough to restore the soil moisture depleted during the long, hot months, ground-water recharge may occur during the fall, though the water table seldom rises as high as it does in the spring. After the fall recharge, if any, the water table declines through the winter, though at a decreasing rate because the decline gradually reduces the slope toward the streams that causes the water to move toward them. and the water table reaches a low point in the spring just before the thaws that send it upward again.

Fluctuations of the water table in a typical humid area having cold winters (Pennsylvania), showing changes in ground-water storage as a result of recharge and natural discharge, are shown in figure 3.

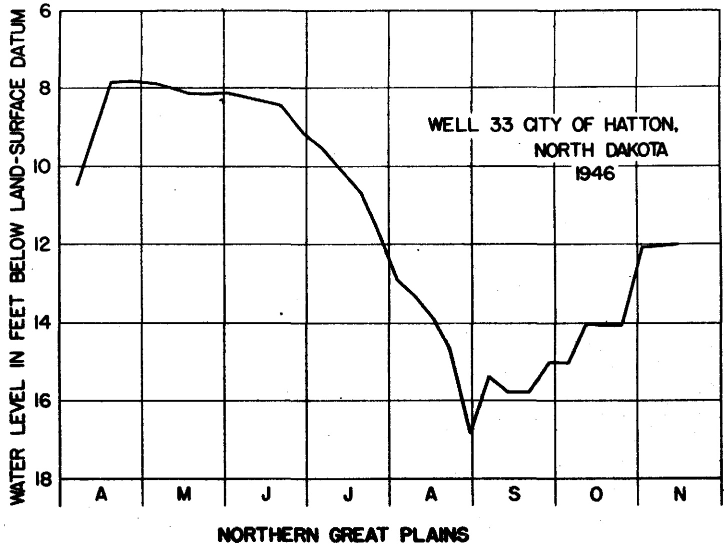
Recharge in the humid but warmer Southeast and South is similar to that in humid areas farther north, except that temporary storage in the form of ice and snow is less important or nonexistent, and recharge occurs whenever rainfall supplies enough water to exceed the higher evapo-transpiration losses and soil-moisture requirements. In the main or continental part of the Southeast recharge occurs mainly during a period of high rainfall in the first few months of the year, and there is generally a second period of high rainfall and a secondary period of recharge in late summer and fall. In the southernmost areas along the Gulf and in Florida the climate tends to be subtropical and a large part of the recharge takes place in the summer and fall, when rains are heaviest. Typical fluctuations of the water table in Florida are shown in figure 3.

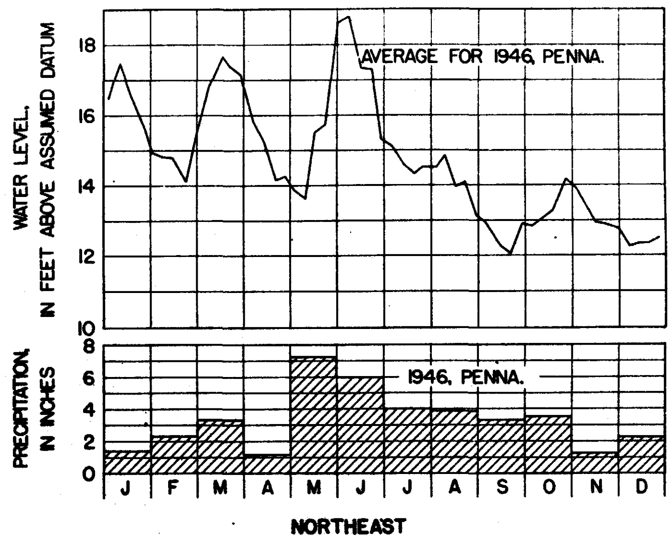
In the great midcontinent Great Plains belt of subhumid to semiarid climate east of the Rockies, ground-water recharge is similar to that in the more humid areas except that it is less because of reduced precipitation and increased evapo-transpiration, and it may be very low or nonexistent in a dry year or even, in the drier parts of the belt, in a normal year. Fluctuations of water level in a typical part of this belt (North Dakota) are shown in figure 3.

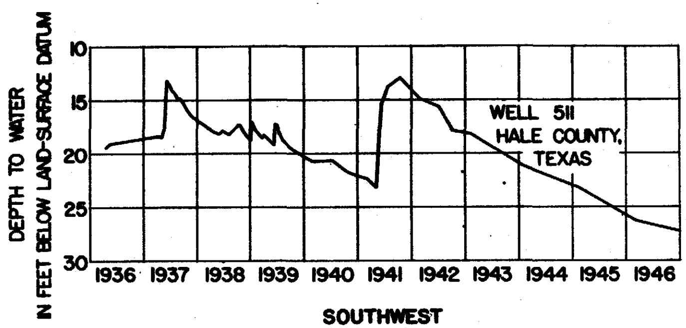
In the arid West, ground-water recharge is greatly different from that in the East. The region is a vast desert, dotted with mountain ranges which receive much more precipitation than the adjacent basins—amounts comparable to those received in the East. The mountains are relatively cool and they are built mainly of dense, impermeable rocks and have steep slopes. Thus, they tend to shed a large part of the precipitation they receive, though even beneath steep mountain slopes there may be enough ground-water storage capacity to even out and prolong considerably the runoff resulting from rainfall and snow melt._/

_/ For example, see Dennis, P. E., Geology of San Antonio Canyon, Calif., in relation to ground-water storage; U. S. Geol. Survey manuscript report; Troxell, H. C., and others, Hydrology of the San Bernardino and eastern San Gabriel Mountains, Calif.; U. S. Geol. Survey water-supply paper, in preparation. Prepared in cooperation with San Bernardino County Flood Control District.

Thus, the mountains act as catchment areas for precipitation and as sources of water for the adjacent desert valleys, which not only receive much less precipitation but are hotter and flatter than the mountains. Only exceptional precipitation on the valley floors themselves is capable of producing direct ground-water recharge. It is believed that, in the average







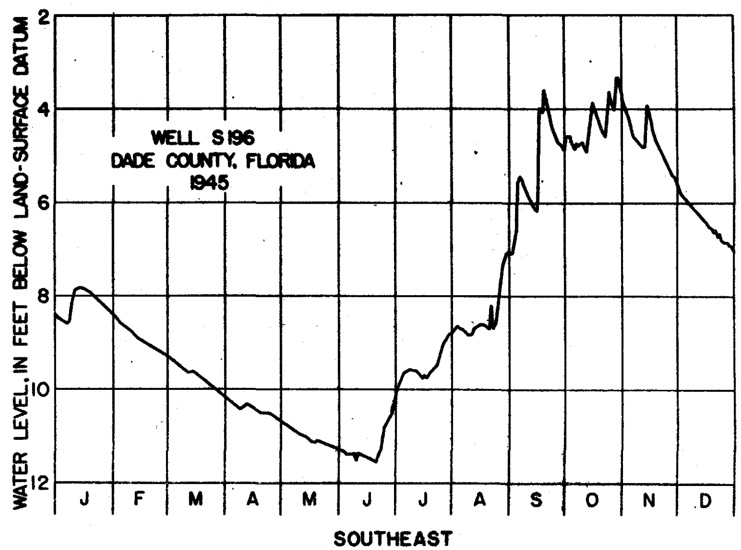


FIGURE 3. GROUND-WATER FLUCTUATIONS IN DIFFERENT CLIMATIC ENVIRONMENTS

year, the direct recharge from precipitation is very small, or, in the hotter areas, even nonexistent.[/] Reasonably good data for the southern High Plains

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[/] Turner, S. F., U. S. Geol. Survey, Personal communication regarding central Arizona, March 18, 1949.

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in Texas,[/] which are semiarid rather than truly arid, show that an average

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[/] Barnes, J. R., and others, Geology and ground water in the irrigated region of the southern High Plains in Texas; Progress Report No. 7: Texas State Board Water Eng., pp. 24-26, March 1949. Prepared in cooperation with U. S. Geol. Survey.

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of only a small fraction of an inch of the roughly 20 inches of precipitation per year reaches the water table, and there is evidence that the recharge takes place mainly in the exceptionally wet years like 1941 and to a very slight extent or not at all in the long intervening periods (fig. 3). The even greater inability of a normal precipitation of 5 to 10 inches to recharge the ground water in the drier valleys farther west is obvious.

The intermountain valleys of the West are basins formed by the downdropping of blocks of the earth's crust when the adjacent mountain blocks were raised. As gradually the one block dropped and the other rose, streams attacked the newly forming mountains and eroded them, reducing their height and filling the basins with rock debris. From the mouth of each valley a stream debouched onto the plain, dropping first the coarser fragments and then the smaller, and carrying the fine sediments to the lowest part of the valley. As the streams built up their beds with the coarser fragments, their level frequently rose above the adjacent plain and the streams breached these "natural levees" and took new courses across the plain. Thus were formed the coalescing alluvial fans, each with an apex of coarse, generally well-sorted gravel at the canyon mouth and, down the slope, crooked stringers of coarse channel deposits fingering out through fine materials deposited adjacent to the channels as the flood waters spread out and lost their force.

All of which goes to explain the existence and importance of the ground-water basins of the West and the way in which they are recharged, in a region where the climate is so dry that one would expect large ground-water supplies to be nonexistent. We have the mountains as sources of surplus water that leaves them by way of streams. We have the adjacent basins filled with alluvium deposited by those same streams and ideally suited to receive water from them whenever they flow. Typically the streams sink into the valley floor soon after they leave the mountains, and the water flows underground to the lower part of the basin where it comes to the surface and either evaporates or flows out of the basin. Here we have our second principal type of ground-water recharge--infiltration from stream flow--and it is the principal way in which recharge occurs in the arid West. The streams are called "losing" or "influent" streams (fig. 4). They can be contrasted with the "gaining" or "effluent" streams typical of the more humid areas, where ground-water recharge from precipitation generally is adequate to keep the water table above the streams and the ground water moving toward them except when they rise sharply in time of flood; then they, too, lose water to the ground as "bank storage," which returns in large part to the streams as their levels fall.

Movement

The subject of movement of ground water is one that is simple in broad outline though complicated in detail. Ground water obeys exactly

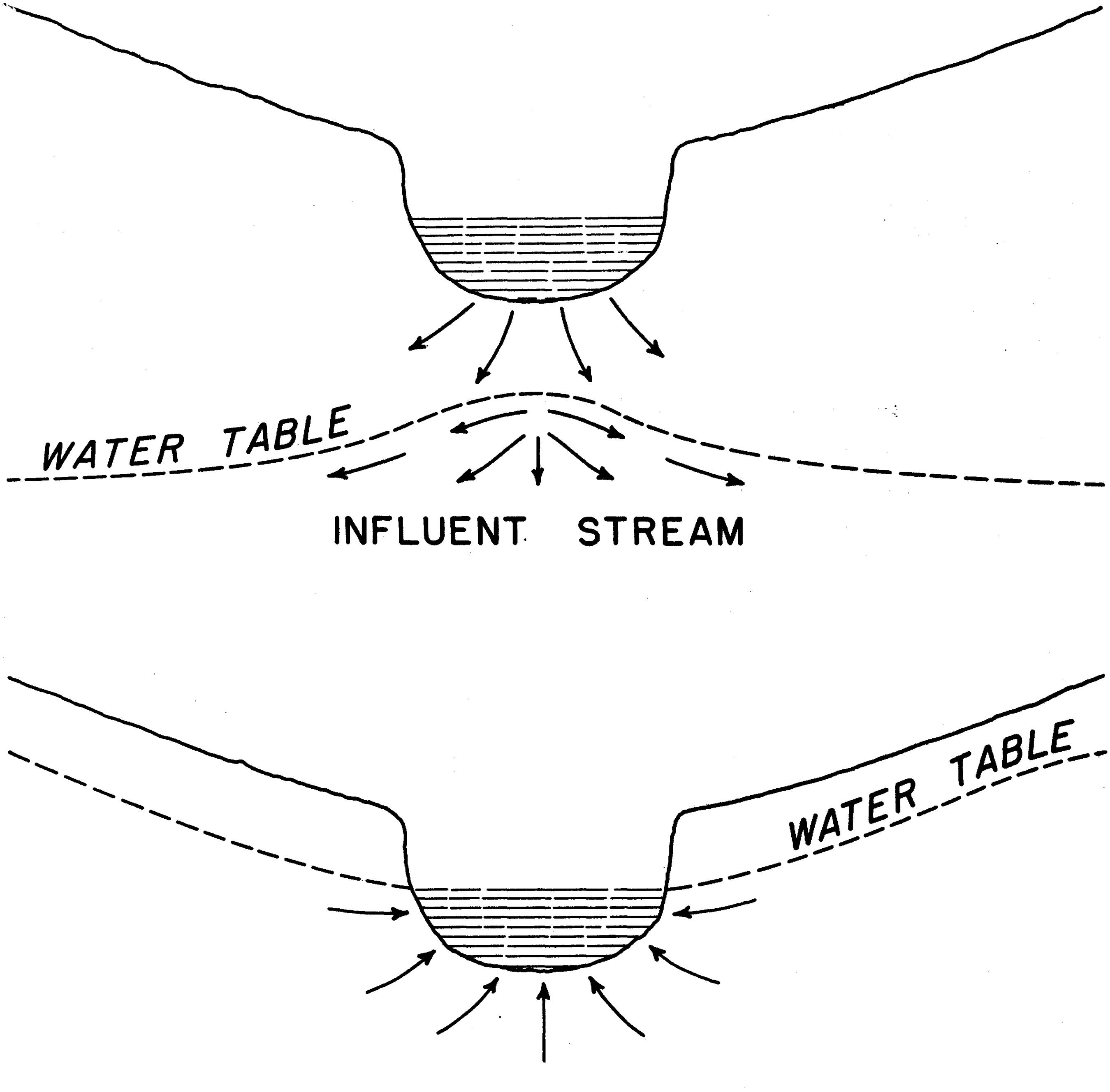

FIGURE 4. DIAGRAM SHOWING RELATION OF INFLUENT AND EFFLUENT STREAMS TO WATER TABLE

the same physical laws as its counterpart on the surface—there are no mysterious, inexplicable movements though it is harder to pin ground-water movements down because they take place out of sight and must be measured indirectly. Both ground and surface water flow always under the influence of gravity, from points of higher potential to points of lower potential, always taking the most direct possible path, which produces the steepest "pressure gradient" and the maximum rate of flow. The one important difference is that ground water generally moves so slowly that the internal friction between its particles is relatively low and its flow is "laminar" or "streamline" or "viscous." In such flow the rate is exactly proportional to the "hydraulic gradient"—the difference in head between two points divided by the distance between them._/ Surface water

_/ Wenzel, L. K., Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods: U. S. Geol. Survey Water-Supply Paper 887, p. 3, 1942.

too can move slowly enough for the flow to be laminar, but ordinarily its velocity is such that there is greater turbulence and thus more loss of head through friction between the water particles. The turbulence does not increase gradually, but rather suddenly when the velocity reaches a certain point that depends upon the size of the conduit and the roughness of its walls. Once this "critical velocity" is exceeded the rate of flow varies approximately as the square root of the hydraulic gradient._/

_/ For example, see Tolman, C. F., Ground water, pp. 190-200, New York, McGraw-Hill Book Co., Inc., 1937; Muskat, Morris, The flow of homogeneous fluids through porous media, p. 58, New York, McGraw-Hill Book Co., Inc., 1937.

Ground water moves wherever there is a hydraulic gradient—a difference in head—between one point and another, and a hydraulic connection through an opening large enough to permit the pull of gravity to overcome the "capillary attraction" between a particle of water and the walls of the opening. Movement of ground water can take place through extremely small pores if the difference in head is great enough, but the finer-grained clays and similar "tight" rocks are essentially impermeable under the gradients that are common in nature.

Practically speaking, however, ground water flows in relatively permeable rocks and between or around relatively impermeable ones. If, in flowing through a body of alluvium, it encounters a buried ridge of tight rock, it is dammed up, rising until it can flow over or around the ridge. Perhaps the ridge is somewhat permeable; then, after the ground water rises high enough on one side there may be enough head to induce flow through the barrier, as in the South Coastal Basin near Los Angeles._/ If the water-bearing

_/ Poland, J. F., Garrett, A. A., and Sinnott, Allen, Geology, hydrology, and chemical character of the ground waters in the Torrance-Santa Monica area, Los Angeles County, Calif. U. S. Geol. Survey manuscript report, 1948. Prepared in cooperation with Los Angeles County Flood Control District and others.

bed is underlain and overlain by tighter materials and grades into similar materials down the slope of the hydraulic gradient, the movement is impeded but the head will build up, inducing movement by slow percolation through the tighter materials, until the ground-water body is "backed up" to its recharge area and spills over to another outlet, after which the head can be built up no more. Water may pass between impermeable beds and be confined under artesian conditions, as outlined previously, and will move so long as there is some hydraulic connection with an outlet and a hydraulic gradient toward that outlet. Where it is confined it may actually flow upward in a bed whose dip is opposite to the hydraulic gradient, but there is nothing more remarkable about this than the upward flow of water in a pipe under pressure. Even under water-table conditions water can flow upward--but always down the hydraulic gradient--as it does to enter a stream cutting and draining an unconfined aquifer (fig. 4). In this case the water in a particular stream line is actually confined between its neighboring stream lines, forming what is somewhat analogous to artesian water at that place.

The movement of water is profoundly affected by and takes place in accordance with the geology--that is, the character and structure of the rocks. This is nothing more than to repeat that water flows in permeable rocks and between or around impermeable ones, following the path of least resistance just like surface water. We cannot hope to cover all the infinite details of rock character and structure that affect the flow of ground water in the different geologic formations of the United States, but we can say once more that water moves through the rocks wherever there is water to do so and openings in the rocks that are continuous to some point of outlet at a lower elevation.

Discharge

If water enters and moves through the rocks it must discharge from them, by one means or another. As in a surface reservoir, the water level rises as water enters a ground-water reservoir until it spills over or until the water is exposed to the air or to plant roots over a broad enough area to be discharged by evaporation and transpiration. Ordinarily discharge of a ground-water reservoir takes place both by outflow of liquid water and by evapo-transpiration, just as in the case of a surface reservoir. The outflow may be to a stream that drains the basin or underground to an adjacent basin, though the latter case is relatively rare and is most common in the alluvial basins of the West. In the East, most of the discharge takes place by liquid outflow to the streams, but substantial evapo-transpiration occurs near the streams where the water table is close to the surface. Where the surface is flat and relatively undissected by streams, the water table tends to build up near the surface, and, because the hydraulic gradient toward the streams is low, the bulk of the discharge may be by evapo-transpiration, as in the Florida Everglades._/

_/ Ferguson, G. E., U. S. Geol. Survey, The plan and progress of recent surface-water studies in the Everglades: Florida Soil Sci. Soc. Proc., vol. 4-A, 1942, p. 84. Prepared in cooperation with Florida Geol. Survey, Dade County, City of Miami, and others.

In the West the type of discharge depends in part on the opportunity for outflow of water in liquid form. Many basins are crossed by, or are the sources of, streams that are able to carry water away, and under natural conditions an important part of the outflow is over the surface. Examples are the Rio Grande Valley in New Mexico and the Central Valley of California. There are, however, many closed basins in the West, particularly in Nevada and Utah, that have no surface outlets. Some have underground outlets through which a part or all of the ground water leaves the basin. The typical closed basin, however, has no underground outlet. It is completely surrounded by tight rocks, and all the water that falls on the basin is ultimately discharged by evapo-transpiration. Each basin has a low spot or "playa" toward which the ground water, as well as any surface flow that may occur during storms, moves and is evaporated from the surface of a dry salt lake—salty because all the mineral matter picked up by the water in traveling over and through the ground is left behind—or transpired by water-loving vegetation that fringes the "playa."

Over a long period, the liquid discharge of a ground-water reservoir is equal to the average recharge minus loss by evapo-transpiration. The storage or impounding effect of the reservoir is such as to "even out" irregularities in recharge, and the larger the reservoir, or, more correctly, the larger its usable storage capacity, the greater the evening-out. In the smaller reservoirs, as in the small, well-drained basins and sub-basins typical of much of the East, the ground-water discharge into the streams varies considerably, being at a maximum during or shortly after periods of maximum surface runoff, but its variation is always less than that of the surface runoff, andthe more capacious the ground-water reservoir the greater the disparity. Figure 5 shows the part of the flow of a typical stream formed by ground-water discharge. Figure 6 shows strikingly the effect on the surface-runoff characteristics of differences in underground storage capacity between two basins near each other in Indiana. The basin of Wildcat Creek is underlain by relatively impermeable glacial drift that has a low rate of intake and a low storage capacity; the basin of the Tippecanoe River contains several lakes and is underlain by thick, permeable glacial deposits capable of absorbing, storing, and paying out water remarkably evenly. Figures 19 and 20 show similar contrasts between the basins of the Mad and Hocking Rivers in Ohio.

In extensive reservoirs, ironing out of fluctuations in recharge may be virtually complete, so that the discharge remains nearly constant. This is particularly true for extensive artesian aquifers. The water table near the outcrop of the aquifer rises and falls with variations in the rate of recharge, but the piezometric surface some distance away toward the discharge area shows almost no fluctuation at all; that which does occur is due to fluctuations in atmospheric pressure and to pumping from wells rather than to changes in the rates of recharge and discharge.

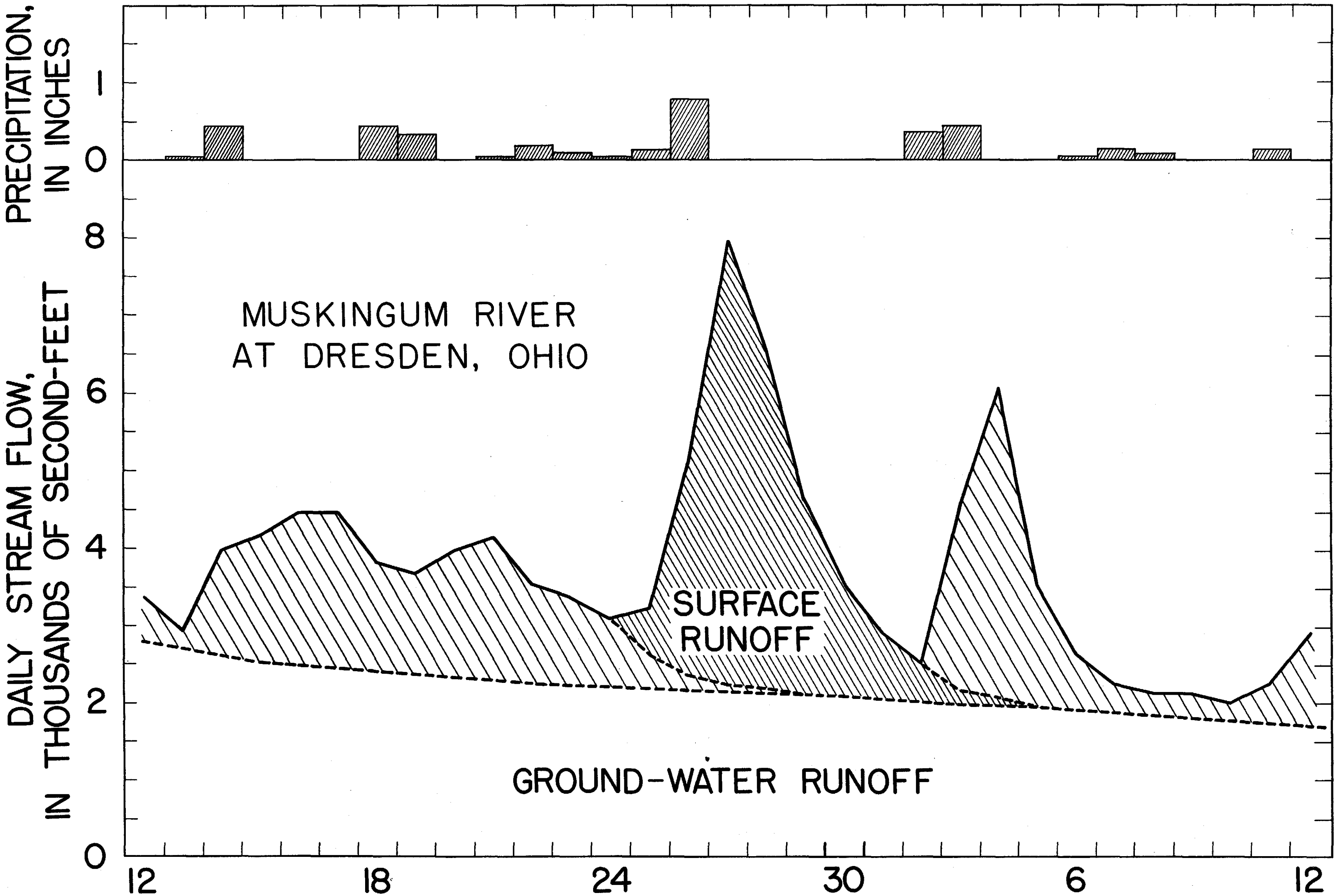

FIGURE 5. HYDROGRAPH OF STREAM FLOW SHOWING SEPARATION OF SURFACE AND GROUND-WATER RUNOFF

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VARIATION IN STREAM FLOW IN BASINS OF CLOSE PROXIMITY

Great Differences Caused By Natural Factors As Shown By Two Streams Only 50 Miles Apart

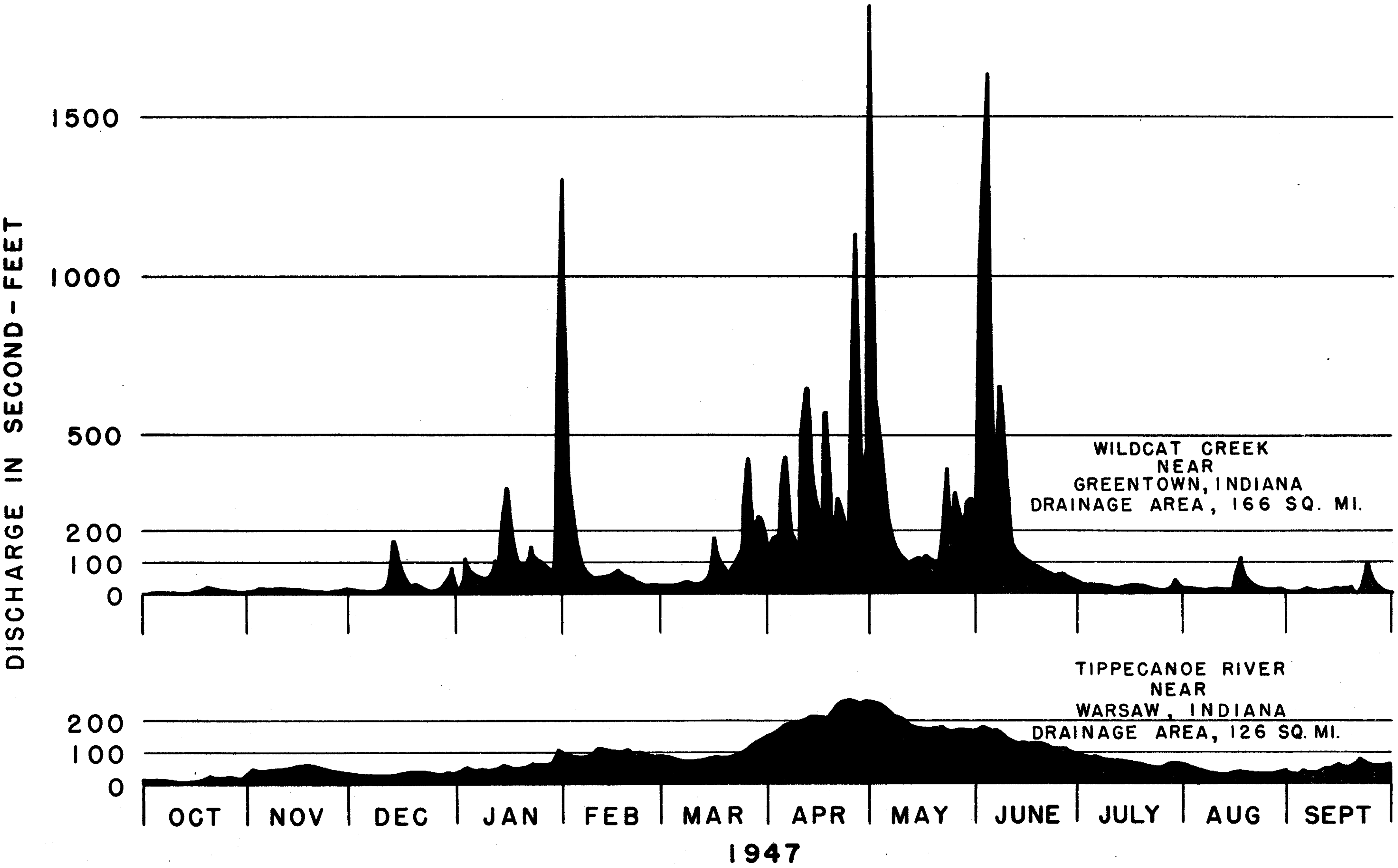

FIGURE 6

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study the effects of observed climatic fluctuations on our water supply and take them into account in planning water use for the future. It does the average farmer - or the resident of New York City - no good when rain is insufficient this year to reflect that the 10-year average precipitation probably will be close to normal. He needs water this year, and information should be gathered to show how storage facilities or supplemental sources of water can be made available to bridge the dry years.

Evaporation and replenishment of soil moisture have the highest priorities in their demands on the available water from precipitation. Only when these demands are satisfied or the maximum rate at which they can occur is temporarily exceeded by rainfall or snow melt, is water available to run off over the land surface or recharge the underground reservoirs. Therefore, when rainfall is less than normal, evaporation and transpiration get a larger percentage of the rainfall and proportionately less water is available to run off over or through the ground.

Whether ground-water recharge or surface runoff has the higher priority on the remaining water depends on the relation of the rate at which water becomes available at the surface to the rate at which the soil and subsoil can transmit it downward to the water table. It depends, therefore, on both the character of the soil and subsoil and the rate of accretion of water at the surface. If the soil and subsoil, and the water-bearing rock below the water table, are permeable and if the rate of accretion is not too high, the bulk of the water will go into the ground and the rate of surface runoff will depend on how quickly the water can move underground to the streams. If the soil and subsoil are tight, the water-bearing rock not very permeable, and the rate of rainfall or snow melt high, the bulk of the available water will run off directly over the surface. In the same area, the proportion will differ with the intensity of rainfall and snow melt;

in different areas with the same rate of accretion of water, the proportion will differ with the underground conditions. In all areas, because both ground-water recharge and surface runoff represent water left after demands of higher priority have taken their toll, their amount and relation to each other will vary even more widely than the rate of accretion of water - that is, more widely than the fluctuations in climatic conditions.

The relation of seasonal availability of water from precipitation in a normal year has been touched on in the discussion of recharge. Here we are concerned mainly with the effects of abnormal conditions, such as exist from time to time everywhere in the United States. Though average precipitation ranges from a few inches to more than 100 inches in the United States,_/ no

_/ Bernard, Merrill, U. S. Weather Bur., Precipitation; Chapter 2 in Hydrology: Nat. Research Council, Physics of the Earth Ser., vol. 9, pp. 32-55, New York, McGraw-Hill Book Co., Inc., 1942.

section of the United States is immune from occasional droughts or floods. During a drought, even in a normally humid area the bulk of the precipitation may be evaporated and transpired and stream flow and ground-water recharge reduced sharply, so that the availability of water depends on the extent to which surface and underground storage can be utilized. During a wet year, there may be a great excess of water over that required to meet the demands for evaporation and transpiration, which tend to be less than normal because of greater humidity, ground-water storage may increase to a maximum, and stream flow also will be greater than normal.

Figure 7 shows how ground-water recharge and stream flow in Ohio, a normally humid area, differed from 1941, when ground-water recharge was nearly lacking and stream flow was reduced sharply because the deficient precipitation was disposed of largely by evaporation and transpiration, to 1943, when precipitation, ground-water recharge, and stream flow were high. The graph of stream flow shows that in

1941 a large part of it was derived from the ground-water reservoirs; if these reservoirs had not been present there would have been a few minor floods in the streams and nothing in between. Too, there are some aquifers along the streams that depend mostly on river water for their recharge, and these had less than a normal supply in 1941 because of the reduced stream flow.

Evidence is accumulating that arid regions are likely to be characterized by infrequent years or period of years in which the bulk of the ground-water recharge occurs, separated by long periods when little or no recharge occurs. This is true both for areas like the High Plains of Texas (fig. 3) where much of the recharge occurs directly from precipitation,_/ and areas like the basins of

_/ Barnes, J. R., and others, op. cit. (Progress report on the High Plains, 1949).

California,_/ where the bulk of the recharge is from stream flow (fig. 8). In

_/ Ebert, F. C., Section on California in Water levels and artesian pressure in observation wells in the United States, Part 6, Southwestern States and Territory of Hawaii: U. S. Geol. Survey Water-Supply Paper 911, pp. 106-108, 1941. Prepared in cooperation with State of California and others.

areas like that covered by figure 8, which is a graph for a well in the Santa Ana River basin, the disparity between wet and dry periods is accentuated by increased pumping in the dry periods and reduced pumping in the wet. Thus, in the West, it appears that it is mainly the abnormal rather than the normal condition which produces the important ground-water recharge. Inasmuch as little or no recharge occurs even in an average year, the reduction of precipitation in a dry year has relatively little effect on ground-water recharge.

The part played by the ground-water reservoirs in meeting our water demands will be discussed more fully later. Here it should suffice to point out that it is the areas underlain by the large and productive ground-water reservoirs that are affected relatively little by extreme climatic fluctuations. There, during

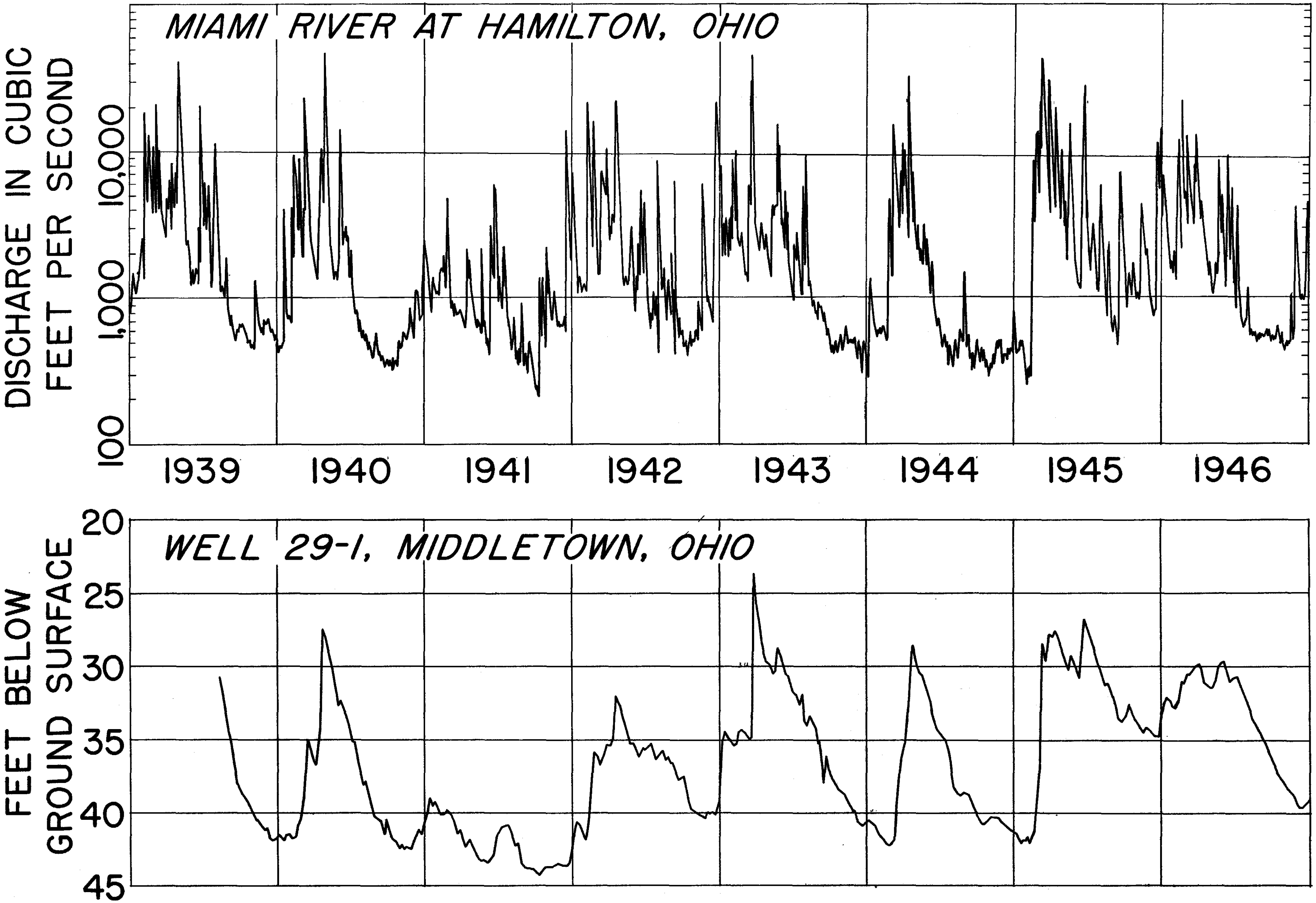

FIGURE 7. GROUND-WATER FLUCTUATIONS AND SURFACE RUNOFF IN A HUMID REGION

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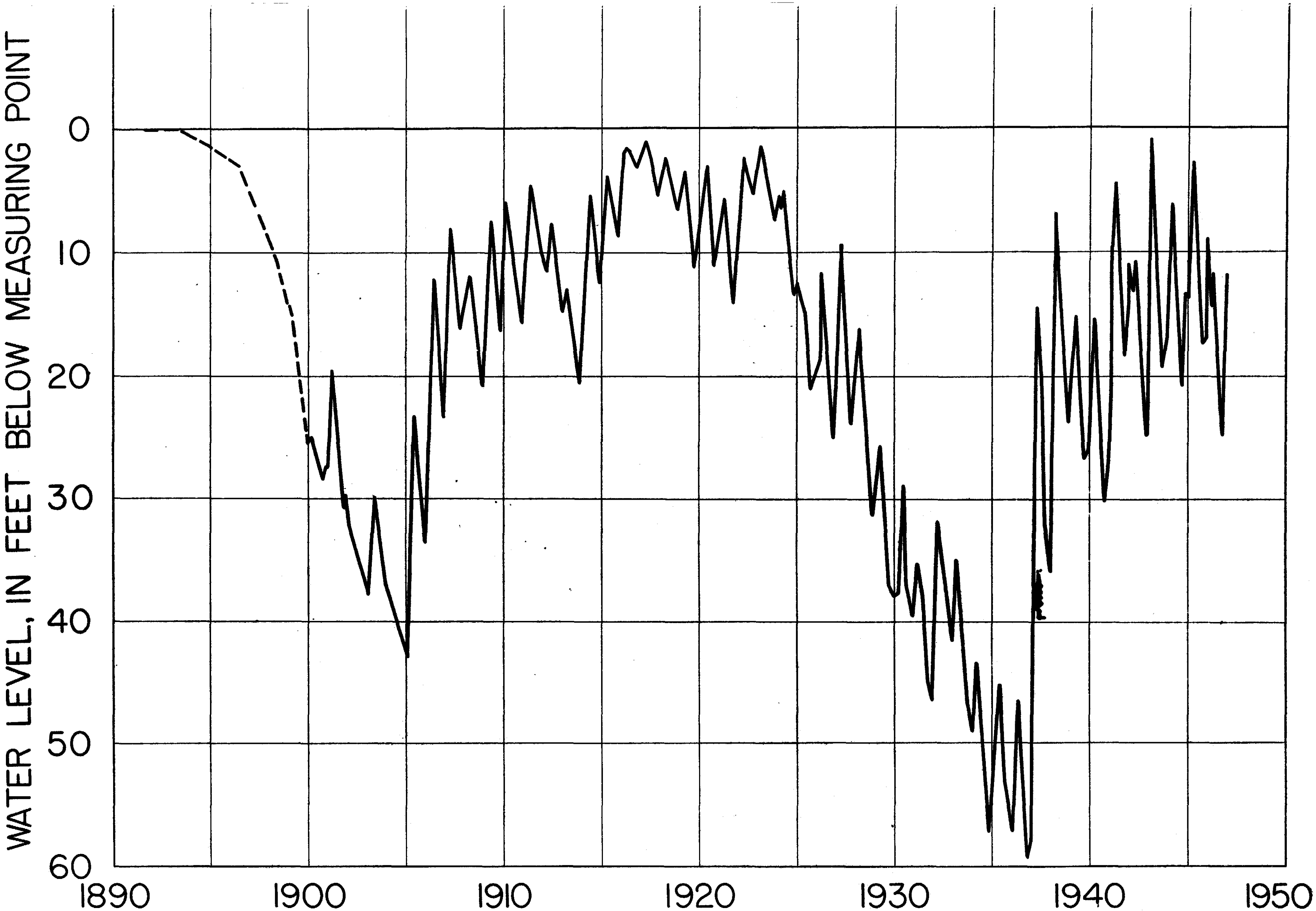

FIGURE 8. GROUND-WATER FLUCTUATIONS IN THE WILLIAMS WELL, SAN BERNARDINO, CALIF., A SEMI-ARID REGION OF HEAVY DRAFT.

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droughts, the ground water is available for use when surface runoff is low and artificial reservoirs are depleted or do not exist at all and it is the ground-water reservoirs that provide whatever stream flow occurs between rains. When the climatic conditions swing to the opposite extreme and too much water is available, the areas with the largest ground-water reservoirs are again fortunate because of the extent to which the surplus water is stored underground and paid out slowly, so that the severity of the floods is moderated (fig. 6).

Ground Water and Stream Flow

The importance of the water-bearing formations as balancing reservoirs in reducing flood peaks and sustaining low flows in streams has been touched on in a general way. We have not yet brought out, however, the actual quantitative importance of ground-water discharge as a source of stream flow - an importance that is not generally recognized. The corollary - the importance of stream flow as a source of ground water - is obvious when it is remembered that streams are the main source of ground-water recharge in the arid West, where water is most precious.

The most spectacular additions of ground water to surface flow are represented by large springs. Meinzer[1] described 65 springs of the first magnitude, which he defined as those yielding an average of 100 cubic feet per second (44,900 gallons per minute) or more. Among the largest are the Thousand Springs and others issuing from lava rocks along the north side of the Snake River between Milner and King Hill, Idaho. The total spring discharge in this 40-mile stretch was 3,885 cubic feet per second in 1902, and in 1918, after the flow had been increased by irrigation

[1] Meinzer, O. E., Large springs in the United States: U. S. Geol. Survey Water-Supply Paper 557, p. 4, 1927.

developments on the uplands, it amounted to 5,085 cubic feet per second.[/] Other

[/] Meinzer, O. E., op. cit., p. 43.

large springs include the limestone springs of the Ozark region of Missouri and those of Florida.

Spectacular as the large springs are, their discharge is but a small fraction of the total flow of ground water through springs and seeps into the Nation's streams. The average annual precipitation in the United States is about 30 inches. Of this, a little more than 21 inches is evaporated and transpired and a little less than 9 inches runs into the ocean.[/] The 9 inches represents an average flow of about

[/] Langbein, W. B., and others, Annual runoff in the United States: U. S. Geol. Survey Circ. 52, p. 5, June 1949.

1,800,000 cubic feet per second. Of this, it is estimated on the basis of the available incomplete data that between one-third and two-fifths, or between about 600,000 and 700,000 cubic feet per second, has passed through the ground-water reservoirs before entering the streams.[/] This is the part that can be discriminated

[/] Langbein, W. B., Personal communication, Mar. 13, 1950.

readily on graphs of stream flow (fig. 5). A large additional part - under some conditions perhaps virtually all - of the remainder may pass through temporary zones of saturation near the surface as "subsurface storm flow" and issue as wet-weather springs and seeps in time to be counted as a part of the "direct surface runoff."

This discussion brings out forcefully the importance of ground water as a contributor to stream flow. But it also emphasizes what has been stated before, that we cannot talk about ground water or surface water but must talk about water. Diversion of water from underground reservoirs, to the extent that it is not returned to them, and to the extent that it is not accompanied by a reduction in evapo-transpiration losses, represents a depletion of stream flow. Thus uses of ground water and surface water are competitive to an extent depending on the net effect on evapo-transpiration, and if we are to keep a balanced approach to the water situation this competition must always be considered.

The competition need not always be destructive, however. Where extensive ground-water reservoirs are concerned, there may be a considerable lag between the time of withdrawal of a large quantity of water from underground storage and the time when the corresponding depletion of stream flow occurs, and the depletion may not occur during the season of low flow in the river, when competition among uses of its water is at a maximum. The greater the storage capacity of the underground reservoir, the greater the lag in the effect on stream flow of withdrawal from or addition to ground-water storage. For example, the flow of the Metolius River, in Oregon, fluctuates relatively little because the underground storage capacity of its basin is exceptionally great; the effects of wet and dry cycles show up with a lag of 5 years or more as compared with those on the flow of the nearby John Day River, whose basin has a much smaller underground storage capacity.[/] There would be a similar delay in the effect of large withdrawals of

[/] McDonald, C. C., and Langbein, W. B., U. S. Geol. Survey, Trends in runoff in the Pacific Northwest: Am. Geophys. Union Trans., vol. 29, no. 3, pp. 394-396, June 1948; Piper, A. M., U. S. Geol. Survey, Runoff from rain and snow: Am. Geophys. Union Trans., vol. 29, no. 4, pp. 516-518, August 1948.

ground water some distance from the river.

Importance of Quality of Water

Water containing absolutely no impurities would be a curiosity in nature, as indeed it would be practically impossible to prepare in a laboratory. Water is the universal solvent - it is capable of dissolving more different substances and more of them than any other solvent. From the instant that its gaseous molecules condense to form droplets in a cloud, it begins to dissolve or absorb things - oxygen, nitrogen, carbon dioxide, and rarer gases from the air, various gases and fine particles of ash resulting from volcanic eruptions, bacteria and plant spores, and even industrial gases and smoke particles resulting from the activities of man. When raindrops fall they already contain substantial quantities of these constituents, though we are accustomed to thinking of rain water as about the purest water there is. Water that falls in frozen form may take on less of these substances, but it, too, is not pure.

From the moment that water reaches the ground and begins to pass over the surface or through the soil and rocks, it attacks them, dissolving or entering into chemical combination with them. Already containing some carbon dioxide, it dissolves more from the soil, adding also some of the complex organic acids resulting from plant decay, and becomes an even more powerful solvent. As laboratory acids go, this solution of carbonic and organic acids is pretty weak, but given time it can do an enormous amount of chemical work. All minerals dissolve to at least a slight extent in water; most are even more susceptible in the presence of the weak acids. The carbonate rocks - limestone and dolomite - that form an important part of the stratified sedimentary rocks of the United States are especially susceptible to solution by water containing carbon dioxide and other weak acids. It is this solution that forms the great caverns like Mammoth and Carlsbad; in a less spectacular way it has operated over the ages past to enlarge the few cracks in many dense, impermeable limestones and convert them into important aquifers, and to make initially good aquifers like the porous Tamiami limestone of the Miami area even better._/

_/ For example, see Parker, G. G., U. S. Geol. Survey, Notes on the geology and ground water of the Everglades in southern Florida: Florida Soil Sci. Soc. Proc., vol. 4-A, 1942, pp. 47-76, Prepared in cooperation with Florida Geol. Survey, Dade County, City of Miami, and others.

Ground water is in longer and more intimate contact with earth materials than surface runoff, and it tends to be more highly mineralized. This tends to limit its usefulness in comparison to that of surface water having a low mineral content. However, the mineral quality of ground water tends to be relatively uniform, which simplifies its treatment where necessary, and the two most common objectionable features, high iron content and hardness, usually can be removed at reasonable cost. Surface water, though generally less mineralized on the average, may fluctuate widely in quality as its make-up varies from nearly pure rain water or snow melt in time of flood to essentially nothing but ground water in periods of minimum flow. This variation, plus sediment content, complicate the treatment of surface water.

Because of the extent to which water is filtered in passing through the soil and rocks, nearly all ground water is of good sanitary or bacteriological quality, whereas surface water is safe to drink without treatment only when it is derived from uncontaminated watersheds. The chief exceptions to the general purity of ground water lie in the cavernous limestone and lava-rock aquifers, where polluted water may pass into and through the ground essentially without filtering, and in shallow, poorly constructed wells located too near sources of contamination such as privies and barnyards.[1]

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[1] Rural water-supply sanitation; Recommendations of the Joint Committee on Rural Sanitation: U. S. Public Health Service, Public Health Repts., Supplement No. 185, 1945.

It goes without saying that water drunk by human beings or used for washing, bathing, or preparing food must be bacterially safe, but for some uses bacterial purity is not essential. Practically every use, however, must take into account the chemical character of the water, though in some it is much less important than in others. Water to be drunk must not contain amounts of iron, chloride, magnesium, and certain others in excess of safe limits for palatability or toxicity. Water used for cooking and washing has some of these and other limitations, principally iron content, hardness, and bicarbonate. Water used for irrigation should not be too highly mineralized nor have an excess of sodium over other alkaline constituents. Water used by industry must meet certain specifications, which vary widely with the use and some of which are much more critical than standards for drinking water. Iron content for dyeing; hardness, sodium, bicarbonate, and silica for high-pressure boilers; and even hardness for canning peas are among the many factors that must be considered.[1] Temperature, though a physical rather than a chemical property,

[1] Moore, E. W., Progress report of the Committee on Quality Tolerance of Water for Industrial Uses: New England Water Works Assoc. Jour., vol. 54, pp. 263, 271, 1940.

is another factor of extreme importance in many uses.

It becomes apparent, then, that in one sense water is not always water. Sometimes the water molecules are there, and plenty of them, but the other molecules and particles mixed in make the water useless, or impossible to treat economically for any use for which water is needed at the time and place concerned. Such water might as well not be available at all unless and until its condition can be changed practicably. In some cases there is not much that can be done to change it, as in an area where all the water is naturally salty, and the water goes to waste or serves only a very low use such as cooling. Where our water supplies have been contaminated as a result of our own actions, however, we must consider whether steps can be taken to reduce the contamination and so to make the water available for useful purposes.

In any event, we can never ignore the quality of the water, which is always a matter of importance and in many cases is the limiting factor rather than the physical presence or absence of needed quantities. Through adequate basic studies of the quality of the water, as related to the geologic and climatic background of the area in which it occurs, we can predict successfully what kind of water will be available; through adequate planning based on these studies, we can use for one purpose water not suitable for others and can make usable water that is unsuitable in its native condition or that has been made unsuitable through our own fault.

EFFECT OF LAND-USE PRACTICES

We have here a subject about as controversial as any in the field of hydrology. At the outset it should be admitted that a complete answer cannot yet be given to the many questions that exist; so far only a fraction of the scientific research necessary to answer them as they relate to the best use of our water resources has been done. But we can say confidently that the research can be done, the questions can be answered, and we can then plan to use our water fully, yet wisely, safeguarding both it and the land for the use of future generations. In this report we can only hope to treat the subject superficially and perhaps point the way to revealing and laying some ghosts.

From the standpoint of water perhaps the most critical question is this-- Is the way we use our land causing our water supply to diminish and floods to increase? We are told that the water table is declining gradually and that our underground reservoirs will eventually go dry. We are told on the one hand that our stream flow is diminishing and on the other that it is too high but at the wrong times. We are told that our climate is changing, for some unknown reason or because we are overcutting our forests; that improper measures of cultivation are causing water to run off too fast and reducing the infiltration to the water table; that the pumping from wells in our industrial cities is lowering the water table under whole States; and so on, and on, and on. How much of all this is true? Some of it is true, in part, and some of it is false. Some of it is true at one place or time but not true at another. To relieve undue public anxiety on these questions, but even more to know where we are going and what we must do to go in the right direction, we must get to the bottom of these matters.

We have discussed the effect on water of climatic fluctuations and have said that there is no reason to believe that there is any permanent trend toward reduced precipitation or increased temperature as a result of natural causes. We can go further and say that there is no reason to believe that the activities of man have had a substantial effect on regional climate. The Weather Bureau has shown that precipitation occurs when favorable conditions are created by the relative movements of huge air masses, and changes in the local moisture content of the air caused by local drainage or cultivation practices are not significant in causing or preventing precipitation._/ The

_/ Kincer, J. B., op. cit. (Is our climate changing?), pp. 19-34.

feasibility of inducing precipitation by seeding clouds with dry ice or other substances is a subject of much interest now, but it remains for the future to determine whether this will be an important factor in our national water situation. We should do everything we can to make artificial precipitation feasible, if at the same time we can demonstrate that we can control it so that the beneficial effects will outweigh any nonbeneficial ones.

Assuming, then, that so far our land-use practices have not changed the climate on a large scale, we must consider what else we may have affected. In some places farm drainage has materially modified the land-water relation. There is no question that soil erosion is a serious national problem. It has sent countless tons of soil from improperly farmed lands or lands that should not be farmed at all down our streams, not only choking our streams and reservoirs but robbing us of a part of our present food-growing capacity. Closely related is the pollution of many of our largest streams with industrial and domestic wastes and mine drainage, making them unsightly, destructive to fish and wildlife habitats, and useless or nearly useless for purposes for which they are needed. We have depleted some of our ground-water reservoirs and contaminated others. All these things must be corrected, and ways must be found to correct them economically and in a coordinated way, so that alleviation of one condition without regard to the effect on others will not create still more problems.

The Geological Survey has been gaging streams since 1888, gradually increasing the coverage until now daily or continuous measurements of stream flow or stage are made at some 6,000 stations on the principal streams and many tributaries. Many of the records are now more than 40 years long and of considerable and increasing reliability for use in forecasting. They show a tendency, in some parts of the country, for the runoff from a given amount of precipitation to decrease slightly._/ Analysis of the records has not yet been complete enough to show the extent to which this tendency may be due to variations in the intensity of precipitation, to increased temperature and correspondingly increased evapo-transpiration, to land-use practices, or to other factors not yet identified. A categorical statement cannot now be made that land-use practices have or have not affected the total runoff, but we can say that, if they have, they have not affected it very much in the country as a whole.

_/ For example, see Hoyt, W. G., and others, Studies of relations of rainfall and runoff in the United States: U. S. Geol. Survey Water-Supply Paper 772, pp. 96-110, 1936; Harbeck, G. E., Jr., and Langbein, V. B., Normals and variations in runoff, 1921-45: U. S. Geol. Survey Water Resources Rev., Supplement No. 2, 1949.

There is a very widespread national impression that the water table is declining the country over. This impression is due to many things, such as reported or observed declines of water level in farm wells, declines in drained areas, declines in irrigated and industrial areas, and the reported drying up of springs. Many of these things have happened, but they have not happened the country over, and where they have happened they can be explained.

Recharge of ground water occurs where both the land surface and the underlying material are capable of transmitting water under the influence of gravity. The highest infiltration rates per unit of area occur where soil is absent or is of negligible importance in either assisting or impeding flow—sand dunes, gravelly river terraces or river bottoms, terranes of cavernous limestone or lava rock, and so on. But the area of such terranes is only a small fraction of the total; most of the water that reaches the water table must pass through the soil to do so. The condition of the soil, therefore, is a critical element of the hydrologic cycle and one that is particularly sensitive to the activities of man. These activities may affect the amount of water entering, stored in, passing through, or discharging from the soil and so may change the natural land-water relationship; they must be taken into account in any attempt to evaluate the reliability and permanence of our ground-water resources.

In this vital field the Soil Conservation Service of the Department of Agriculture has made a substantial beginning through study at experiment stations throughout the country, particularly at such research centers as that at Coshocton, Ohio. Much remains to be done, however, in the field of infiltration and ground-water recharge and the effects on them of cultivation and land-use practices in general. The research by the Soil Conservation Service needs to be expanded greatly, therefore, together with that by the Forest Service, and that by the Geological Survey in the little-known field of unsaturated flow above the water table.

Perhaps, at this point, we should nail down one important point. The measurements of water level in about 15,000 wells observed by the Geological Survey and cooperating agencies show that, in areas not affected by artificial withdrawals, there is no measurable tendency for ground-water levels to decline. The levels go down in dry periods and up in wet, but on the average they remain about the same._/ Most of the observation-well records are not as long as the

_/ For example, see a symposium on fluctuations of ground-water level, published in Am. Geophys. Union Trans., 1936, pt. 2, pp. 337-390.

more complete stream-flow records, but the few long records show no long-term tendency for the water table to decline except as affected by pumping and other withdrawals--for example, records on Long Island extending back nearly 50 years and occasional prior records made as early as 1851._/

_/ Leggette, R. M., U. S. Geol. Survey, Long-time records of ground-water levels on Long Island, N. Y.: Am. Geophys. Union Trans., 1936, pt. 2, pp. 341-344. Prepared in cooperation with New York Water Power and Control Comm.

Water levels have declined in many areas of withdrawal, even in farm wells where the amount withdrawn is only a fraction of that recharged on the farm itself. Such declines may be due to increased pumping, the extent of which the farmer himself may not realize. Thus, when the well "goes dry" he believes that there has been a general decline of the water table, not realizing that with his new electric pump he is withdrawing more water than he ever did before, and that water levels must decline when pumping increases. On farms where drainage is practiced the water table is lowered, as intended, and the lowering may be reflected in the farmer's well.

A part of the widespread impression of decline of the water table on the farm is due to the survey made in 1910 by W J McGee, who obtained data on declines in water levels in a large number of wells throughout the United States and published figures on average declines._/ O. E. Meinzer,_/ however, showed

_/ McGee, W J , Wells and subsoil water: U. S. Dept. Agr., Bur. Soils Bull. 92, 1913.

_/ Meinzer, O. E., U. S. Geol. Survey, Review of the work of W J McGee on ground-water levels: Am. Geophys. Union Trans., 1936, pp. 386-390.

that the declines were more apparent than real, for the data were based on measurements made in the fall, the season when water levels in most parts of the country covered are normally at their lowest stages, and in 1910, a dry year in much of the country. These levels were compared with the farmers' statements, based largely on memory rather than measurements, of original water levels. Under these conditions it would be natural for a farmer to remember and report the highest springtime stage in a wet year. Thus the assumptions on which McGee's report were based were erroneous, but the report had a profound effect that still persists.

Observational data on the effects of drainage ditches are few. If properly installed, they, of course, accomplish their intended purpose, to lower the water table and permit cultivation earlier in the year, or cultivation where it would not be possible otherwise. The water drained reaches the streams sooner than formerly, and its total quantity may be greater because the lowering of the water table tends to reduce evapo-transpiration losses. If a ditch taps an extensive aquifer far from a natural outlet, many months or even years may be required for the water table to become adjusted to the new level of discharge. In most drained areas, however, the natural outlets are not far away and the adjustment may be expected to be essentially complete within a year or two. The time required can even be determined in advance by existing formulas,_/

_/ For example, see Ferris, J. G., U. S. Geol. Survey, A quantitative method for determing ground-water characteristics for drainage design: Am. Soc. Agr. Eng. Jour., in press. Prepared in cooperation with Michigan Geol. Survey Div.

if the necessary hydrologic data are obtained. There is no evidence that the water table tends to be unstable at its new, lower level, once the adjustment has been made.

The effects on the hydrologic cycle of removal of native vegetation and subsequent cultivation are widely discussed and disputed. It should be made clear that the field is a complex one in which there is much passionate conviction but, so far, only a fraction of the scientific data that must be collected to answer the question. Under certain conditions of geology, soil, and climate, improper land management can lead to erosion of the soil, hardening and tightening of the subsoil, reduction of infiltration to the water table accompanied by its lowering and the drying up of springs, and increases in flood peaks—in short, conversion of a useful area into a useless and even harmful one. How extensive such conditions are should be discovered by systematic investigation, and the causes of and best remedies for them should be determined. The Soil Conservation Service has made substantial progress in these studies. It should be stressed that the same practices do not produce the same results in different areas, so that it is necessary to predetermine, by adequate research, the results to be expected under given conditions, in order to produce the result intended and not another.

Forests have been widely regarded as protectors of the soil and safeguarders of our water supply. There is no question that they play an important part in our national water economy. However, the impression is widespread that removal of forest vegetation can have none but evil effects on water; this thought has been carried even further, to the point where it is assumed that planting of "shelter belts" in areas not now forested will increase precipitation and total water supply. The idea as to increased precipitation has been pretty well dispelled,_/ and some of the other ideas are being

_/ Kincer, J. B., op. cit. (Is our climate changing?).

adjusted to the facts developed by research of the Agriculture Department, the Weather Bureau, the Geological Survey, and their cooperating agencies.

For example, it has long been a popular belief that deforestation automatically is reflected by reduced infiltration to the water table. Where the deforestation is accompanied by destruction of the soil and great reduction of its infiltration capacity there is no question that this can occur. However, it does not occur everywhere, and it does not follow automatically in every case that restoration of the infiltration capacity of the soil will be reflected in a rise of the water table. In experimental areas in Colorado and California, comparison of the water yields of small drainage basins that were deforested with those of adjacent basins that remained forested showed that both total and low-water runoff were increased in the deforested basins._/ The increase

_/ Bates, C. G., U. S. Dept. Agr., Forest Service, and Henry, A. J., U. S. Weather Bur., Forest and stream-flow experiments at Wagonwheel Gap, Colo.: U. S. Weather Bur. Supplement 30, 1928; Wilm, H. G., and Dunford, E. G., Effect of timber cutting on water available for stream flow from a lodgepole pine forest: U. S. Dept. Agr. Tech. Bull. 968, 1948; Hoyt, W. G., and Troxell, H. C., U. S. Geol. Survey, Forests and stream flow: Am. Soc. Civil Eng. Trans., 1934, pp. 1-30; discussions, pp. 31-111.

in total runoff was as expected because the trees, which formerly used large quantities of water, were gone. That low-water runoff increased was revealing, however, because it comes from ground-water storage; thus deforestation in these cases actually led to an increase in ground-water recharge. In the Coweeta National Forest, N. C., it was discovered that total runoff was increased by deforestation by approximately the amount of water formerly used by the trees,_/ and the increase was accompanied by a rise of the water table._/

_/ Hoover, M. C., U. S. Dept. Agr., Forest Service, Effect of removal of forest vegetation upon water yields: Am. Geophys. Union Trans., 1944, pt. 6, pp. 969-975.

_/ Munns, E. N., U. S. Dept. Agr., Forest Service, personal communication, Jan. 12, 1950.

In all cases it has been found that the runoff decreases rapidly as vegetal growth is renewed.

This is not an argument for deforestation; forests have incalculable value for economic and esthetic reasons as well as for protecting the soil. However, it points to valuable principles for application in land and forest management. It emphasizes also that scientific research tends to disclose facts not even suspected in popular thinking--facts that sometimes point in a direction opposite to previous beliefs. We have here, therefore, considerable evidence that unlimited reforestation may not be the answer to our water problems; following up these thoughts a little, we can see promise that proper land management may be able to increase the water yield of a drainage basin without introducing undesirable conditions; and that in some areas now devegetated and in need of soil conservation it may be economically preferable to revegetate them with small plants._/

_/ Croft, A. R., U. S. Dept. Agr., Forest Service, A water cost of runoff control: Jour. Soil and Water Cons., vol. 5, no. 1, pp. 13-15, January 1950.

What should come out of this discussion of land-use practices is not that we should suddenly abandon one tightly held line of thought and take up another. Rather it is that we should realize how little we really know about this vast field and should make it our business to support and to do the tremendous amount of scientific research that remains to be done before we can predict that one land-use practice will produce one result and another, another; we can then plan confidently our future practices knowing what we are doing.

GROUND WATER AS AFFECTED BY USE

Under "Ground water in nature" we considered mainly the part played by ground water in the hydrologic cycle under natural conditions. Now let us consider in a general way the modifications introduced by artificial withdrawals from or additions to the underground reservoirs by man. Conditions in specific areas will be described in later sections of this report.

Effects of Withdrawal from Wells

Under natural conditions the ground-water reservoirs, like natural surface reservoirs such as lakes, are in a state of approximate dynamic equilibrium. Their levels rise in wet periods and fall in dry, but over a long period the water added to them is balanced by discharge from them. The withdrawal of water from wells represents a new discharge imposed on the natural system, and it must be balanced by an increase in recharge or a decrease in natural discharge, or both. Until it is so balanced, water is withdrawn from storage and the ground-water levels decline. Ultimately, if the withdrawal is not in excess of the extent to which recharge can be increased and natural recharge reduced, a new state of equilibrium is reached. If the withdrawal, however, is greater than can be balanced in this way, the loss of water from storage continues until the water levels are drawn down to the bottom of the aquifer at the point of withdrawal, or to the lowest practicable level of pumping, after which the yield is gradually reduced until a state of equilibrium is reached for that particular aquifer and that particular distribution of wells.

It must be remembered that the ground-water level must decline if water is to be withdrawn from a well, in order that a hydraulic gradient may be set up to induce water to flow to the well to replace that withdrawn. When withdrawal begins the water level in the well is lowered and a "cone of depression," with apex at the well and pointing downward, begins to form around the well. The slope of the cone is steeper near the well than farther away, for the same quantity of water must pass through an ever-decreasing cross section of the aquifer as it approaches the well. The shape of the cone of depression depends on the water-carrying capacity of the aquifer. Steep, narrow cones form in the less permeable aquifers, shallow ones in the more permeable aquifers.

At first all the water comes from storage in the aquifer, and the cone of depression must deepen and grow laterally as more and more water is withdrawn, until it diverts to the well an amount of water equal to the rate of withdrawal--water that formerly discharged elsewhere or that represents increased recharge. The rate of growth of the cone of depression depends on the storage capacity--specific yield or coefficient of storage--of the aquifer; the larger that capacity the more slowly the cone grows. Thus, as discussed previously, it grows much more slowly in an unconfined or water-table aquifer than in an artesian aquifer, whose storage capacity may be hundreds of times smaller. This might be a good place to point out that, if the withdrawal is large enough, the water level in an artesian aquifer may be drawn below the bottom of the upper confining bed, so that the upper part of the aquifer is unwatered, the piezometric surface in the unwatered part is now a water table and the storage capacity typical of water-table conditions exists there, and the rate of lowering of the water level is correspondingly reduced. In any event, however, the cone of depression must grow until it diverts enough water to supply the well.

It is apparent, then, that aquifers differ in the amount of water that can be withdrawn with a given amount and rate of lowering of the water level; that for a given lowering more water can be withdrawn from widely spaced than from closely spaced wells; and that to obtain the maximum effect in increasing recharge and reducing natural discharge, wells should be located as close as practicable to the areas of recharge and natural discharge. It is important, therefore, to be able to predict the effect on a given aquifer of withdrawal of water from wells, in order to guard against spacing wells so closely together that their cones of depression will overlap unduly, causing excessive local drawdown when more widely spaced wells would yield the same amount with less drawdown. Such predictions are possible through analysis of data obtained in pumping tests, by methods developed principally by the Geological Survey in the last 20 years./

/ For example, see Wenzel, L. K., op. cit. (Water-Supply Paper 887) and other papers listed in Partial bibliography of published and unpublished literature concerning ground-water hydraulics and applications of quantitative methods, with special reference to work of the Ground Water Division, U. S. Geol. Survey (duplicated), 9 pp., December 1948.

The two fundamental properties that govern the effect of artificial withdrawal on an aquifer are its water-carrying capacity or "transmissibility" and its storage capacity, the "specific yield" for water-table conditions and the "coefficient of storage" for artesian conditions. The transmissibility is determined by the permeability of the material and its thickness; that is, for equally permeable material a given aquifer will carry twice as much water under a given hydraulic gradient than one half as thick. The unit of permeability commonly used by the Geological Survey for field work is the number of gallons of water a day that will pass through a strip of the aquifer 1 foot thick and 1 mile wide under a gradient of 1 foot per mile. The transmissibility is the permeability times the thickness of the aquifer in feet.

The units used for storage capacity have been defined previously, under "Water-table and artesian conditions."

These fundamental properties of an aquifer can be determined by properly controlled pumping tests. They vary from aquifer to aquifer and from place to place within an aquifer, so that for an adequate determination a number of tests must be made. When the coefficients have been determined, they can be used to predict the effect on any aquifer of withdrawing water from any given combination of wells. The formulas originally used assume an extensive and uniform aquifer in which all withdrawals are from storage. Later modifications permit the successful prediction of the effects of withdrawal on nonuniform aquifers and those limited by barriers or having areas of recharge or discharge within the range of pumping effect./

/ For example, see Ferris, J. G., U. S. Geol. Survey, Ground-water hydraulics as a geophysical aid: Michigan Dept. Conservation, Geol. Survey Div. Tech. Rept. 1, March 1948.

We have said that the ground water withdrawn comes from storage until the withdrawal is balanced by an adjustment in the recharge and natural discharge of the aquifer. Let us now discuss a little how such an adjustment takes place.

Natural discharge from an aquifer occurs because there is a hydraulic gradient toward an outlet where water is discharged in liquid form or is evaporated and transpired. The effect of artificial withdrawal is to lower the water level and reduce the gradient toward the areas of natural discharge. Thus the quantity of water flowing toward them and discharging in them is reduced and the difference represents water diverted to the well. If the lowering goes far enough the gradient toward the natural discharge area may be reversed, and, instead of water discharging into a stream, water will seep from the stream into the aquifer. This is "induced recharge."

Artificial withdrawal increases the hydraulic gradient toward the well from areas of recharge and increases the flow of water from them. If the rate of recharge already is at a maximum, because of limited precipitation or the inability of the soil to transmit water to the water table as rapidly as the aquifer is able to transmit it away to discharge areas under natural conditions, the lowering of the water level caused by artificial withdrawal cannot increase the recharge. Thus the withdrawal, if it is to be stabilized, must be derived entirely from a reduction in natural discharge. This condition is common in the arid West. If, under natural conditions, however, the potential recharge is in excess of the rate at which the aquifer can transmit water to areas of natural discharge, the water table is built up as high as it can get and surplus water entering the ground spills over into streams crossing the recharge area or is evaporated and transpired. This is "rejected recharge," and it is common in the humid East. If the water table is lowered in the recharge area as a result of artificial withdrawal, space is provided in the aquifer for some of the water that formerly spilled over, and the increased amount of water can travel through the aquifer because of the increased gradient set up by the artificial withdrawal. This, too, is "induced recharge," and here too the process can be carried far enough to prevent water from spilling over in the recharge area and even to induce surface water flowing from areas upstream to infiltrate from the stream channels into the ground. Such "induced infiltration" from streams has always occurred where wells penetrating permeable aquifers near a river have been pumped heavily enough to reverse the natural gradient of the water table, but it is being done deliberately on an increasing scale along such rivers as the Ohio.[/]

[/] Kazmann, R. G., River infiltration as a source of ground-water supply: Am. Soc. Civil Eng. Proc., vol. 73, no. 6, pp. 837-853, June 1947.

Addition of Water to Underground Reservoirs

Man's activities result in the addition of water to underground reservoirs in several ways besides the "induced recharge" or "induced infiltration" described above as resulting from withdrawals from wells. Deliberate addition of surface water or of used ground water, by methods known as "artificial recharge," will be discussed later. Here we will consider briefly more or less unintentional additions which, however, are of great importance in some areas.

Application of water for irrigation is an important source of ground-water recharge in most irrigated areas. It is necessary to apply more water than is needed to meet the demands for evaporation and crop growth. This excess water or "excess irrigation" serves the purpose of keeping the soil flushed of the salts that accumulate when the water is evaporated and transpired and that otherwise would soon make the soil unfit for cultivation. The excess water, called "irrigation-return water," seeps downward to the water table, adding to the ground-water supply. If not diverted by pumping it may flow to and drain into a stream and be used over again for irrigation or some other purpose, or flow to an area where it is disposed of by evaporation and transpiration.

The irrigation-return water represents an important source of water, and in planned irrigation projects it is always taken into consideration. It does not represent new water, but it reduces the net requirement. It is not enough, however, simply to determine the amount of irrigation return and figure on its reuse. Each time the water passes through the soil its load of dissolved mineral matter increases, and its use must be regulated so that it does not become too concentrated. Where the water initially applied has a low mineral load and where the soil and rocks through which it passes contribute little mineral matter, the water can be reused several times before it becomes too concentrated. However, reuse must be limited where the original water is high in mineral matter, the soil and rocks contain much soluble material or are so tight that water moves through them slowly and has more opportunity to dissolve the soluble material, and water of good quality is not available for diluting the irrigation-return water. Such conditions are common in the arid West.

Where the soil and rocks are not very permeable, or permeable but drain slowly because of the distance to natural outlets, irrigation with surface water may raise the water table, so that the low spots become waterlogged, the water is discharged by evapo-transpiration, and the salts in it accumulate in the soil, forming "alkali" conditions. Installation of adequate drainage systems or pumping to lower the water table is necessary here.

Thus the gradual accumulation of salts in the water and the waterlogging of land represent potential problems associated with nearly all irrigation projects, which must be solved through careful study of all these factors if the projects are to be successful. An excellent example is the Salt River Valley in central Arizona.[/] There the application of irriga-

[/] McDonald, H. R., Wolcott, H. N., and Hem, J. D., Geology and groundwater resources of the Salt River Valley area, Maricopa and Pinal Counties, Ariz. U. S. Geol. Survey mimeographed rept., February 1947. Prepared in cooperation with Arizona State Land Dept.

tion water raised the water table, waterlogging the lower tracts and threatening others. Wells were installed and pumped to lower the water table, and the water was used for additional irrigation. Soon the practice of pumping water for irrigation was recognized as a practical way of accomplishing subdrainage and reuse of water and was extended until now the area is seriously overpumped. Overpumping need not occur where a project is properly planned and carried out on the basis of adequate basic information, however, and the pumping of water to keep the water table down and to provide for reuse of water can and should be an integral part of many projects.

The building of surface reservoirs may result in the addition of water to underground reservoirs. The addition may be inadvertent, where a reservoir thought to be tight proves to be leaky, and may even lead to failure of the reservoir to meet its intended purpose.[/] It may be deliberate, where the

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[/] For example, see Bean, R. T., Geology of the Roswell artesian basin, N. Mex., and its relation to the Hondo Reservoir. Manuscript report in files of U. S. Geol. Survey. Prepared in cooperation with Bur. Reclamation, State Engineer, and State Bur. of Mines, and to be published by one of the State agencies.

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permeability of the reservoir bottom is recognized and the effect of the reservoir in adding to the ground-water supply is taken into account or, indeed, may be the purpose of building the reservoir, as in the case of the Santa Clara Valley Water Conservation District in California.[/]

[/] Conkling, Harold, and Bryan, E. N., Santa Clara investigation: California Dept. Public Works, Div. Water Resources Bull. 42, 1933.

In humid areas where the water table normally slopes toward the streams, a body of water impounded by a reservoir may act as a dam for a time. It causes the ground water flowing toward the reservoir to accumulate until, together with water seeping from the reservoir, it fills up the new "underground reservoir" that has been formed, and eventually spills over at the new, higher level. The effects may be beneficial in raising the water table and making ground water more easily available, or harmful, if the rise of the water table waterlogs valuable land, but they should always be considered when a reservoir is planned. Such "bank storage" in some reservoirs is equivalent to a sizable fraction of the surface storage; it adds to the total storage and must be taken into account in planning additions to or withdrawal from storage. Studies by the Geological Survey now in progress show that the "bank storage" in Lake Mead is equivalent to roughly an eighth of the total storage capacity.[/]

[/] Langbein, W. B., U. S. Geol. Survey, personal communication, Apr. 3, 1950.

Management of Ground-Water Reservoirs

We have seen how important the ground-water reservoirs are as storers of water and regulators of stream flow. We have described some of the effects of artificial withdrawals and additions and have hinted at the possibilities of locating wells so as to increase recharge and reduce wasteful natural discharge and thus to make the reservoirs more useful to man. Let us now consider more fully the management of our underground reservoirs as a part of our national water economy. Practically all of our ground-water problems are the result of mismanagement, in the sense that uncontrolled development has produced results that were not forseen, or could not be foreseen on the basis of available information. Without proper management we can look forward to nothing more than aggravation of existing problems and creation of new ones. With it we can modify the natural regime to make the ground-water reservoirs take in more water and waste less; we can utilize their storage function more effectively to reduce wasteful and destructive flood runoff in the wet season and periods of wet years and make more water available in the dry season and in periods of dry years when it is needed most; in short, we can make ground water assume its rightful place in our economy, a place it must occupy if we are to continue to grow in strength and wellbeing.

Sustained Yield *vs.* Mining

Each ground-water reservoir has a sustained yield to which it can be developed for human use. This quantity or feasible rate of withdrawal depends on the natural characteristics of the aquifer--its extent, thickness, permeability, and structure, and those of overlying and underlying rocks (some aquifers are so sealed off as to be virtually unreplenishable); the topography, climate, soils, and vegetation in its recharge and discharge areas; and the extent to which water is available for recharge and the opportunity for natural discharge as governed by these and other factors. It is not a fixed quantity; it depends importantly, too, on the way in which the developments are made, for one distribution of wells and pumping may produce a total dependable yield vastly different from another, depending on the effect in increasing recharge and reducing natural discharge and on the overlapping of cones of depression. By designing his installations properly man can accelerate the circulation of water through the reservoirs and thus make them take in more water, available for useful purposes, than they did in their natural state.

Opposed to sustained yield is mining of ground water. There is always some withdrawal of water from storage as the hydraulic gradients adjust themselves to new conditions of discharge. However, if the reservoir is to be used indefinitely at its sustained yield, the loss in storage can go to the feasible limit but no farther; the water levels will decline to a stage at which, on the average, they will be stable, though in the operation of the storage function of the reservoir they may be alternately drawn below that average stage and made to recover above it. In the mining of ground water, however, there is a progressive loss of storage as the withdrawal continues to exceed the extent to which natural losses can be salvaged and increased recharge can be induced, and ultimately the ground-water levels reach the lowest practicable stages, after which the withdrawal must be reduced to the rate of natural recharge less remaining natural discharge. An extreme example of an area in which ground water is being mined is the southern High Plains in Texas, _/ where water currently is being withdrawn at more than 20 times the

_/ Barnes, J. R., and others, op. cit. (Progress report on the High Plains).

estimated rate of replenishment. Mining even more important quantitatively, though not on a percentage basis, is occurring in such areas as central and southern Arizona _/ and in California. _/ Still other cases of mining, involving

_/ Turner, S. F., Arizona ground-water levels continue decline. U. S. Geol. Survey press release, Aug. 12, 1949, based on annual report on ground-water levels in Arizona for 1948. Prepared in cooperation with Arizona State Land Dept.

_/ Poland, J. F., U. S. Geol. Survey, Ground water in California: Am. Inst. Min. and Met. Eng. Trans., vol. 187, Min. Eng., pp. 279-284, February 1950. Prepared in cooperation with California Dept. Public Works, Div. Water Resources, and others.

withdrawal of water from artesian storage rather than under water-table conditions such as prevail in the High Plains, have occurred in the artesian basin formed by the Dakota sandstone _/ in the Great Plains and probably in parts

_/ Wenzel, L. K., and Sand, H. H., Water supply of the Dakota sandstone in the Ellendale-Jamestown area, N. Dak.: U. S. Geol. Survey Water-Supply Paper 889-A, 1942. Prepared in cooperation with North Dakota Geol. Survey

of those formed by the Cambrian and Ordovician sandstones of Illinois, Wisconsin, and adjacent areas.

Thus, considering both sustained yield and mining, we might adopt the concept of optimum yield - the rate at which it is found feasible and desirable to withdraw water from an underground reservoir. We can regard each reservoir as raw material, which we can adapt for our uses as scientific investigation and thoughtful planning make it possible -- even to the extent of exhausting stored water in aquifers having little replenishment, if we decide that the best interests of an area or of the Nation as a whole are thus served.

We have used freely the words "feasible," "practicable," and "desirable." These bring into the concept of optimum yield the factor of economics. We may do only what we can afford to do. We can provide installations for increasing recharge and reducing natural discharge, for drawing the water levels down the needed amount to achieve these objectives, but we can do these things only if they are profitable. Obviously, certain uses of the water we develop will be more profitable than others, and a given use will be more profitable at one time than another. In Chicago water is lifted as much as 800 feet from wells for industrial use. In California it is lifted from depths of more than 500 feet in some places for irrigating valuable crops; if the prices of the crops decline enough the pumping cost will be excessive and irrigation from wells will have to be reduced or stopped. Thus we have another and controlling variable in determining the optimum yield of an aquifer.

The maximum usefulness of the ground-water reservoirs over an indefinite period obviously calls for development of their sustained yield rather than mining of their water. In certain cases, however, involving aquifers whose perennial yield is small, at least so far as the present distribution of withdrawals is concerned, it may be necessary to modify this principle. Take the case of the southern High Plains of Texas, for example. There the average annual replenishment of the ground water, though not known accurately, can be taken as roughly 50,000 acre-feet, and the current withdrawal is considerably more than a million acre-feet per year and is increasing rapidly. Furthermore, the natural discharge of roughly 50,000 acre-feet, by seepage and evaporation at the edges of the plains and in some of the valleys crossing them, has not yet been appreciably reduced because the lowering of the water table has not extended that far; thus, essentially all the current withdrawal is from storage. On a perennial basis the net withdrawal obviously cannot exceed the rate of recharge, and even this assumes that all natural discharge would be stopped. Now, if it had been possible to control the withdrawal right from the start, should it have been restricted to the rate of recharge? This would have left untouched the vast amount of stored water accumulated over the past, amounting to perhaps 150 million acre-feet in the irrigated part of the southern High Plains.[1]

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[1] Barnes, J. R., and others, op. cit. (Progress report on the High Plains), p. 41.

Here is an example of one of the most difficult problems of hydrology, economics, and philosophy that we have to face. We must first determine the available water resources of such areas--the amounts of water that can be withdrawn under various conditions and the lengths of time over which the withdrawal can be continued under each procedure considered. Then it must be decided whether the stored water is to be mined in whole, in part, or not at all. In the southern High Plains of Texas we are already committed to mining the water; what can we do to obtain supplemental water, or to provide substitute gainful activities if it is not practicable to get enough water to continue irrigation? The High Plains problem is a classic example of one that has developed because the limitations on the ground-water resource were not recognized. If we can solve it we will have a key to solving others, but so far no long-range effective solution has been devised for the High Plains, and every year of delay will make the solution more difficult. One thing is certain: In such areas we should know the hydrologic facts early in the game; no intelligent action can be taken without them.

The Central Valley of California is another even more important hydrologic and economic unit faced with the problem of overdevelopment of ground water. Here the solution appears to be in sight, and though it will be expensive it will provide an example of what can be done where the water of a major basin is regarded as a unit and plans are devised for using it to the maximum practicable extent. In simple terms the problem is one of replenishing the depleted ground-water supply of the southern San Joaquin Valley, indirectly through use of water from the wetter northern part of the Central Valley. The present overdraft in the southern San Joaquin Valley is on the order of 1 to 1-1/2 million acre-feet per year.[/] It is proposed to divert flood water

[/] Poland, J. F., op. cit. (Ground water in California).

from the San Joaquin River, now used farther north, to underground storage in the southern part of the valley, making it available for use when stream flow is low, and to replace the part of that water now used farther north with water from the northern part of the Central Valley. The underground reservoir of the northern or Sacramento Valley part of the Central Valley will also be used to store flood water for later use.[/] Thus the underground reservoirs

[/] Poland, J. F., op. cit. (Ground-water storage capacity of the Sacramento Valley).

will be drawn down in dry periods and refilled in wet, so that there will be neither a shortage of water in dry seasons and years nor waste of nor damage from flood waters in wet seasons and years. The project is not yet "out of the woods." The present plans will not provide as much water as is needed, and many procedures remain to be planned and carried out. For example, it has not yet been determined where and how the artificial recharge of the underground reservoirs can be carried out most effectively and economically, but the difficulties are recognized and the basic geologic and hydrologic studies are under way. Here we will have a key to the kind of scientific investigation and analysis, economic thinking, and engineering planning that we will have to provide for similar problems elsewhere.

Salvage of Natural Waste

An important part of the management of our water resources must be the salvage of natural waste. We have spoken of salvaging "rejected recharge" and reducing the natural discharge of the ground-water reservoirs, and so making more water available to wells. Part of the rejected recharge and natural discharge goes into streams and serves to maintain their flow, and part of it goes into the air through evapo-transpiration. To the extent that ground-water withdrawals can be made to reduce the wasteful loss by evapo-transpiration, we can increase the net usable water supply, even if those same withdrawals result in some depletion of stream flow. Let us recall that, of the approximately 30 inches of precipitation received annually in the United States, about 21 inches is discharged by evaporation and transpiration and only 9 inches in liquid form into the ocean. The amount of water discharged by evapo-transpiration is staggering. On a hot midsummer afternoon in the United States, water is pouring into the air, molecule by molecule, at a total rate equivalent to more than 10 times the maximum recorded flood flow of the Mississippi River at Vicksburg. We can hope to recover only a small fraction of this, but all we recover will be added to our potential maximum water supply. An important part of what we can recover is that discharged by evapo-transpiration from the ground-water reservoirs. The much larger amount discharged from the soil without ever reaching the water table is less easily reducible, but we should make thorough studies to determine where and how a part of it can be salvaged, as through land-use practices that will reduce the loss without injuring the soil or reducing crop growth.

On the basis of meager, incomplete data, it is estimated that phreatophytes (water-loving plants whose roots tap the water table or the capillary fringe above it) grow on some 15 million acres in the 17 Western States and discharge perhaps 20 to 25 million acre-feet of water annually._/

_/ Robinson, T. W., Areas and use of water by phreatophytes in the Western United States. Unpublished memorandum in the files of the U. S. Geol. Survey, Jan. 7, 1949. Prepared in cooperation with State Engineer of Nevada.

This figure includes only phreatophytes that have no beneficial use; beneficial ones, the most important of which is alfalfa, are excluded. Also not included, of course, is the use by upland vegetation of soil moisture that never reaches the water table, the total amount of which is many times larger.

The 20 to 25 million acre-feet essentially wasted by phreatophytes in the 17 Western States is about half again as great as the annual flow of the Colorado River. Though the Colorado is not even among the first 20 rivers of the United States in flow,_/ its importance in the arid Southwest is attested by the vigor of the current dispute over distribution of its waters.

_/ U. S. Geol. Survey Circ. 44, Large rivers in the United States, p. 5, May 1949.

The importance of studying, evaluating, and developing as fully as possible an additional source in the West whose total amount is greater than the flow of the Colorado is equally obvious. Not all the water used by phreatophytes in the West can be salvaged, perhaps not even the major part, but a substantial amount can be and will have to be if the development of the West is not to be stifled by lack of water.

Artificial Recharge

Artificial recharge is the addition of water to underground reservoirs by man. It represents a means of increasing the practicable rate of withdrawal, where it proves to be necessary and feasible. Inasmuch as we have already discussed "induced recharge" or "induced infiltration" and the addition of water through irrigation, this discussion will be brief and will be limited to the deliberate rather than the incidental addition of water. The different methods are discussed and numerous references are given in a paper by Sayre and Stringfield._/

_/ Sayre, A. N., Chief, and Stringfield, V. T., Senior Geologist, Ground Water Branch, U. S. Geol. Survey, Artificial recharge of ground-water reservoirs: Am. Water Works Assoc. Jour., vol. 40, no. 11, pp. 1152-1158, November 1948.

The two principal methods of recharge are those known generally as "water spreading" and the injection of water through "recharge" or "return" or "injection" wells. Water spreading at present is used on the largest scale in California. There, water from streams is passed over permeable ground as a sheet or in basins or furrows. Ordinarily flood water is used, but if it contains much sediment it may be bypassed until the flow is reduced and becomes clearer. In some cases the natural channels of the streams themselves are used for recharge by release of stored water from reservoirs, inasmuch as the principal recharge occurs from the channels anyway. In this way flood water, flowing at a rate exceeding the infiltration capacity of the channel, is stored in surface reservoirs. Later it is paid out at a rate no more than enough to satisfy the infiltration capacity of the channel, with perhaps an excess to meet surface irrigation requirements in and downstream from the recharge area.

Artificial recharge by "water spreading" already is important in the West and will play an increasingly vital part in water-resources management, as in the Central Valley of California. Similar practices are followed to some extent in the East and Middle West, as at the Runyon Waterworks and the Duhernal Reservoir in New Jersey, the Des Moines Waterworks in Iowa, and the Dayton Waterworks in Ohio. It is practiced also to a considerable extent in Europe. _/

_/ Sayre, A. N., and Stringfield, V. T., op. cit.

Artificial recharge through wells is much less important on the basis of total quantity recharged, but in the areas where it is practiced it is vital as a means of conservation. The outstanding area is Long Island, N. Y., where, in accordance with a State law, the Water Power and Control Commission requires that ground water used for cooling and other noncontaminating uses be returned to the ground. _/ The amount returned through more than 300 wells

_/ Brashears, M. L., Jr., U. S. Geol. Survey, Artificial recharge of ground water on Long Island, N. Y.: Econ. Geology, vol. 41, p. 503, 1946. Prepared in cooperation with New York Water Power and Control Commission.

and several pits has amounted to more than 60 million gallons a day during the summer. In 1949, a total withdrawal of 270 million gallons per day was reduced to a net of about 150 million gallons per day by return to the water table of about 120 million gallons per day through artificial-recharge wells and pits, septic tanks, etc.

At Louisville, Ky., two plants producing industrial alcohol during the war were forced to recharge their wells artificially to maintain an adequate yield. They used cold city water from the Ohio River during the winter, thus not only increasing the supply but providing water that was colder than average and thus more effective for cooling, the principal use._/

_/ Guyton, W. F., U. S. Geol. Survey, Artficial recharge of glacial sand and gravel with filtered river water at Louisville, Ky.: Econ. Geology, vol. 41, p. 644, 1946. Prepared in cooperation with Kentucky Dept. Mines and Minerals and City of Louisville.

Such recharge with cold city water derived from a surface source has great promise, where aquifers are depleted by concentrated pumping in industrial cities and where city authorities will cooperate by supplying water at a special rate. Most water plants in such cities can produce surplus water cheaply in the winter, when the normal demand is low, and could sell it for artificial recharge at a rate low enough to make the practice attractive.

Artificial recharge through wells is practiced widely in parts of Florida, so far not so much to increase the supply as to dispose of storm water and industrial wastes._/ The water and wastes are discharged into

_/ For example, see Unklesbay, A. G., and Cooper, H. H., Jr., U. S. Geol. Survey, Artificial recharge of artesian limestone at Orlando, Fla.: Econ. Geology, vol. 41, no. 4, pt. 1, pp. 293-307, June-July 1946. Prepared in cooperation with Florida Geol. Survey.

cavernous limestones, creating, in some places, problems of contamination./

/ Op. cit., p. 300.

Artificial recharge through wells has been practiced on a smaller scale in several other places, including Indianapolis, Ind.,/ and Hopewell,

/ McGuinness, C. L., U. S. Geol. Survey, Ground-water resources of the Indianapolis area, Marion County, Ind.: Indiana Dept. Conservation, Div. Geology, January 1943.

Va./ At Camp Peary, Va., Cederstrom/ made an experiment on a well

/ Cederstrom, D. J., U. S. Geol. Survey, personal communication, April 17, 1948.

/ Cederstrom, D. J., Artificial recharge of a brackish-water well, U. S. Geol. Survey mimeographed report, 1947. Also printed in the Commonwealth (Va.), December 1947. Prepared in cooperation with Virginia Geol. Survey.

normally yielding water moderately high in chloride, showing that fresh water could be recharged and recovered without excessive mixing with the high-chloride water.

In a unique development on the island of St. Thomas, in the Virgin Islands, rain water is to be collected from the paved runway of the airport and recharged through an infiltration gallery into a thin sandy aquifer that now contains only brackish water.

Artificial recharge, especially that through wells but including that by water spreading, is complicated by clogging of the recharge well or basin by sediment in the water or by growth of bacteria and algae, except where the recharge is into cavernous rocks that are not readily clogged. Where clogging occurs, provision must be made for periodic cleaning of the wells or scraping of the sides and bottoms of the recharge basins, or for treatment of the water to prevent clogging.

Complications are introduced also by geologic conditions. For example, permeable materials capable of absorbing water freely may underlie the surface, but unfortunately they may be separated from the depleted aquifer below by impermeable clay. Complications of this kind exist in the West Basin near Los Angeles, Calif., where artificial recharge appears to be necessary but will have to be done through wells or shafts because the aquifer is capped by materials of low permeability._/ Similar conditions

_/ Poland, J. F., Garrett, A. A., and Sinnott, Allen, op. cit. (Torrance-Santa Monica area, Los Angeles County, Calif.) pp. 459-472.

exist in part of the upper San Joaquin Valley where artificial recharge is to be practiced,_/ and detailed geologic studies are now under way to

_/ Livingston, Penn, Ground-water features of the San Joaquin Valley, Calif.; a review of published and unpublished reports and papers. U. S. Geol. Survey duplicated report, January 1944. Prepared in cooperation with the Corps of Engineers, U. S. Army.

determine the areas where it can be carried out, as mentioned previously.

The cost of artificial recharge varies widely. That done through wells is most expensive per unit of water recharged. However, in concentrated industrial districts the cost of land for recharge basins may be prohibitive, so that if artificial recharge is practiced at all, it must be through wells. In all cases, of course, it is practiced where it forms a means of maintaining a necessary water supply more economically than by importing water from another source.

Salt-Water Encroachment and Contamination by Wastes

So far the discussion of the effect on ground-water reservoirs of the activities of man has related largely to the effects in lowering water levels, increasing recharge, reducing natural discharge, etc.--effects involving mainly the quantity of water involved. In some areas, particularly along the coast, limitations on the withdrawal of ground water are imposed by the possibility of encroachment of salty water, rather than by such factors as pumping lift. In some other areas there is contamination by wastes.

Where permeable materials are in contact with the sea, the salt water tends to fill them up to sea level except as it is depressed by fresh water that literally floats on the heavier salt water. The physical principle that governs the relation is that of the U-tube, in which one column is filled with salt water and the other with fresh. The fresh-water column must be higher than the salt because the fresh water is lighter, and it is higher in proportion to the difference in specific gravity. The specific gravity of sea water varies considerably but averages about 1.025, or about 1/40 heavier than fresh water. Thus, the fresh-water column must be about 1/40 higher than the salt. Inasmuch as the top of the salt water is at sea level, a column of salt water is balanced by a column of fresh water 41 feet high, of which 40 feet is below sea level and 1 foot above. That is to say, if near the coast the water table or piezometric surface of fresh water in an aquifer open to the sea is 1 foot above sea level, there theoretically will be 40 feet of fresh water below sea level; if 2 feet, 80 feet of fresh water, and so on. There is never quite 40 feet below sea level for each foot above because there is always some mixing near the contact, increasing the specific gravity of the fresh water so that less than the full 41 feet is required for balance to exist.

The fresh water-salt water balance exists where any aquifer is open to the sea, whether unconfined or confined. Building up of the fresh-water "lens" is possible, of course, because friction prevents the water from running into the sea so rapidly as to dissipate it. For a given rate of fresh-water accretion, the more permeable the aquifer the thinner the lens; for a given permeability, the greater the accretion the thicker the lens.

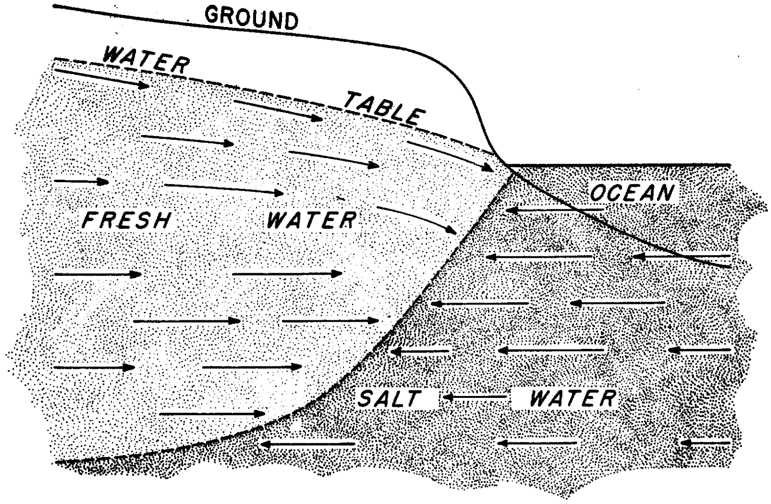
When water is withdrawn from the aquifer the fresh water-salt water contact eventually rises 40 feet for each foot the fresh-water head is lowered, as shown in figure 9. There is a lag, of course, corresponding to the time required for the water to be withdrawn from storage as a result of formation of the cone of depression.

Most artesian aquifers along the coast were filled or nearly filled with salt water several times within the last million years as a result of rises of sea level during interglacial stages of the Pleistocene epoch or Great Ice Age. These aquifers were flushed of part or all of the salt water during glacial stages, when the sea level was lowered, depending on their permeability, the amount of fresh water available for recharge, and the freedom with which water could pass through their undersea extensions, where they commonly grade into less permeable materials. However, many of them, in the parts near or under the sea, have not been flushed completely and still contain water which, though not so salty as sea water, is still too salty for most uses.

This water encroaches on wells in exactly the same way as sea water when the withdrawal is so heavy as to create a hydraulic gradient between the part of the aquifer containing salty water and the wells.

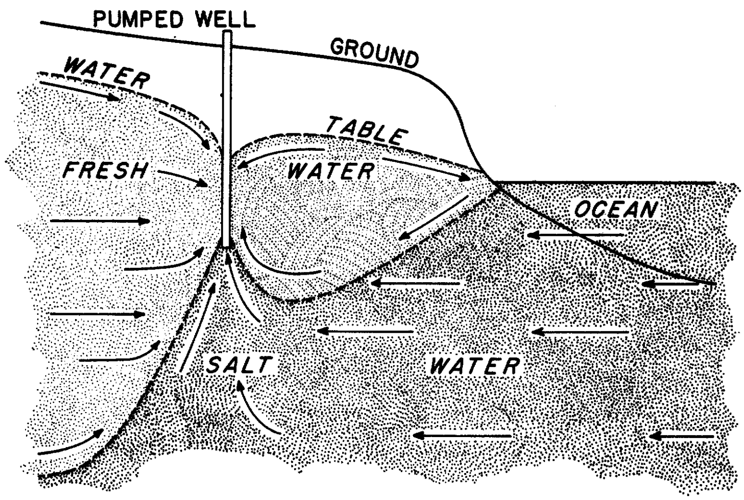
In order for withdrawal of fresh water near the sea to be safe, therefore, it must be at such a rate that, through the full thickness of the fresh-water aquifer, the head will remain high enough between the wells and the part of the aquifer containing salt water to prevent the salt water from rising into or moving toward the wells. This does not mean that the water levels cannot be lowered below sea level at the wells; they can be lowered as far as desirable or practicable so long as the head remains high enough between the wells and the salt water. Obviously, the more productive and heavily recharged the aquifer, the less the head needs to be lowered to produce a given quantity of water and the more water is available to flow around the cone of depression to maintain adequate head between the wells and the salt water.

In the past most withdrawals of fresh ground water near the coast were made without recognition of these principles, and in many places salt water has encroached sooner or later as the fresh-water head has been lowered and the stored fresh water replaced by salt water. Among the important areas where salt- or brackish-water encroachment has occurred are western

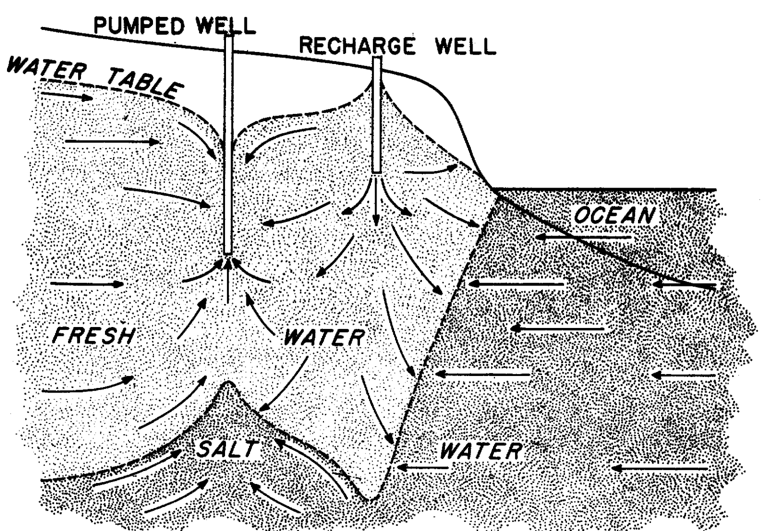


NATURAL CONDITIONS

IDEALIZED DIAGRAM SHOWING RELATION OF FRESH WATER TO SALT WATER IN A COASTAL AREA



SALT INTRUSION



A REMEDY

Long Island (Brooklyn), N. Y., _/ Miami, Fla., _/ Mobile, Ala., _/ the Torrance-

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_/ Brashears, M. L., Jr., U. S. Geol. Survey, Artificial recharge of ground water on Long Island, N. Y.: Econ. Geology, vol. 41, no. 5, pp. 503-516, August 1946. Prepared in cooperation with New York Water Power and Control Commission.

_/ Brown, R. H., and Parker, G. G., U. S. Geol. Survey, Salt-water encroachment in limestone at Silver Bluff, Miami, Fla.: Econ. Geology, vol. 40, no. 4, pp. 235-262, June-July 1945; also Parker, G. G., and others, Water resources of southeastern Florida: U. S. Geol. Survey water-supply paper, in preparation. Prepared in cooperation with Florida Geol. Survey, Dade County, City of Miami, and others.

_/ Peterson, C. G. B., U. S. Geol. Survey, Ground-water investigations in the Mobile area, Ala.: Geol. Survey Alabama Bull. 58, 1947.

Santa Monica _/ and Long Beach-Santa Ana _/ areas near Los Angeles, Calif.,

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_/Poland, J. F., Garrett, A. A., and Sinnott, Allen, op. cit. (Torrance-Santa Monica area, Calif.).

_/ Poland, J. F., and others, Hydrology of the Long Beach-Santa Ana area, Calif., with special reference to the watertightness of the Newport-Inglewood structural zone. U. S. Geol. Survey duplicated rept., June 1946. Prepared in cooperation with Orange County Flood Control District and Water District, Los Angeles County Flood Control District, and City of Long Beach.

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and the Hawaiian Islands, especially the Honolulu area, Oahu. _/ In these and

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_/ Stearns, H. T., and Vaksvik, K. N., U. S. Geol. Survey, Geology and ground-water resources of the Island of Oahu, Hawaii: Hawaii Div. Hydrography Bull. 1, May 1935. See also Bull. 2, geologic map; Bull. 3, bibliography; Bull. 4, records of wells; Bull. 5, supplement. See also Palmer, H. S., Univ. Hawaii, The geology of the Honolulu ground-water supply: City and County of Honolulu, Board of Water Supply, 1946.

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other areas where salt-water encroachment has occurred or is threatened, the geologic and hydrologic conditions, the distribution of wells, and the possible methods of solving the problem differ widely, so that each represents a separate case. All must be studied, however, in the light of the general principles described.

Encroachment of water of undesirable quality occurs inland as well as along the coast, wherever such water can find access to an aquifer or is already present in a part of it and is induced to flow toward wells. Many of the closed or partly closed alluvial basins of the West are characterized by the dry salt lakes or playas described previously. The water beneath and adjacent to the playas has been concentrated by evaporation and may be even saltier than sea water. Wells located too near the playas, drilled too deep, and pumped too heavily may be salted in exactly the same way as wells near the coast. In the Tularosa Basin, N. Mex., the ground water in most of the basin is salty and fresh water is available only in scattered areas around the edge.[1] The development of fresh water, once it is located by

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[1] Meinzer, O. E., and Hare, R. F., Geology and water resources of Tularosa Basin, N. Mex.: U. S. Geol. Survey Water-Supply Paper 343, 1915. Prepared in cooperation with New Mexico Agr. Exper. Sta.

geologic study and test drilling, is constantly complicated by the problem of salt-water encroachment, as in the search for an adequate water supply in the vicinity of Alamogordo.[1]

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[1] Murray, C. R., Memorandum on the possibilities of developing ground water for the Alamogordo Army Air Base. Manuscript report in files of U. S. Geol. Survey, April 1947. Prepared in cooperation with State Engineer of New Mexico.

Ground water of poor quality occurs in humid areas as well as arid. The artesian sandstones of the Chicago area contain highly mineralized water at depth and to the south, down the dip of the beds, and there is a limit to which fresh water can be obtained and, once obtained, pumped so as to avoid encroachment of the poorer water.[1]

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[1] Anderson, C. B., The artesian waters of northeastern Illinois: Illinois Geol. Survey Bull. 34, 1919.

In a large interior region underlain by stratified Paleozoic sandstone, shale, limestone, and, in places, coal beds, extending from New York southwestward to Tennessee and Alabama and westward to the Great Plains, the rocks typically contain water of poor quality at depths more than 100 feet or so below the level of streams, so that heavy pumping may induce poor water to encroach on or rise into the wells. In the northern part of this region the Paleozoic rocks are overlain by glacial drift that contains many good aquifers and is the principal source of water. In the southern part ground water of good quality is scarce in many places./

/ Meinzer, O. E., op. cit. (Water-Supply Paper 489), p. 311.

Water of poor quality may be present in a stream and may encroach on adjacent wells. For example, the water of the Arkansas River is salty below Great Bend, Kans., and tends to contaminate the ground water in the adjacent alluvium, which is of good quality where precipitation is the principal source of recharge. At Wichita, Kans., public-supply wells tapping the alluvium of the Arkansas River were abandoned in favor of wells drilled in another aquifer distant from the river./

/ Williams, C. C., and Lohman, S. W., U. S. Geol. Survey, Geology and ground-water resources of a part of south-central Kansas, with special reference to the Wichita municipal water supply: Kansas Geol. Survey Bull. 79, pp. 169-183, July 1949.

Water of poor quality in water-bearing formations generally is native to the area concerned, but chemical contamination through man's activities has affected some aquifers. For example, a considerable part of the salt in the ground water in the Arkansas Valley area has resulted from dumping of brine from oil wells into the river or into pits in the alluvium;

some contamination has occurred also through wells tapping salty water under pressure in rocks below the alluvium, which has moved through the wells into the alluvium. Chromium-bearing waste contaminated certain industrial wells at Waterbury, Conn.,_/ during the war. Disposal of arsenic-bearing waste

_/ Unpublished data in files of U. S. Geol. Survey.

contaminated certain wells at the Pine Bluff Arsenal, Ark._/ Even the

_/ Unpublished data in files of U. S. Geol. Survey.

spilling of gasoline or leakage from storage tanks may contaminate ground water, as in a recent case at Arlington, Va._/

_/ Cederstrom, D. J., The Arlington gasoline-contamination problem. U. S. Geol. Survey mimeographed rept., May 14, 1947. Prepared in cooperation with Virginia Geol. Survey.

On the whole, the ground-water reservoirs are inherently safer from contamination by industrial wastes than are surface-water bodies, though cases of contamination can be expected to increase in number under some conditions, as where there is increased practice of "induced infiltration" along streams containing impurities that are not removed by the natural filtration. They are even safer from pollution by organic wastes because of the natural filtration that tends to remove bacteria even where it has no effect on dissolved chemicals. However, contamination once introduced is more difficult to remove from underground reservoirs than from surface water, so that great vigilance is necessary to prevent it.

Salt-water encroachment can occur in streams as well as underground reservoirs. Fresh surface water flowing into salt water tends to mix with it more freely than does ground water, but in places there is a remarkable lack of mixing. In tidal streams the fresh water tends to flow over the heavier salt water, and at high tide there may even be a landward flow of salt water beneath seaward-flowing fresh water. Obviously, depletion of the fresh-water flow by drought or by withdrawal for human use will cause the salt water to move landward until it may enter intakes installed for man's use, or may even contaminate ground-water bodies. For example, at Miami, Fla., reduction of fresh canal flow, caused by drainage practices and intensified by drought, permitted sea water to flow along the bottom of the Miami Canal to a point opposite the main public-supply well field, where it flowed out into the permeable limestone and contaminated the wells, principally on one occasion in 1939 but also several times later.[/]

[/] Parker, G. G., and others, Water resources of southeastern Florida: U. S. Geol. Survey water-supply paper, in preparation.

GROUND WATER AND THE NATIONAL ECONOMY

Water is the life blood of our economy and national life. It enters into everything we do or hope to do. The object of our national water policy must be to provide sufficient water for present uses and for the future so long as our Nation is to endure. To do so we must appraise our needs and determine our ability to meet them.

The United States is used to plenty of water. Our per-capita use undoubtedly exceeds that of any other major nation. Both total and per-capita use have increased at a tremendous rate, and so long as water can be made available at reasonable cost they will continue to do so. A century ago the per-capita use of water probably was only a few gallons per day.[1] The total per-capita use now can only be guessed at because of the lack of reliable data, but it may approach, or even exceed, 1,000 gallons per day, for a total of something over 125 billion and perhaps even 200 billion gallons per day. This is for uses excluding hydroelectric-power generation, navigation, and recreation. An amount of water equivalent to roughly four-fifths of the total runoff passes through hydro-power plants (much of it, of course, the same water passing through plants at successively lower elevations), but here the water suffers only a change in position from a higher to a lower elevation, which would happen anyway, and except for its loss of potential energy in so falling its usefulness is not impaired.

[1] Sayre, A. N., U. S. Geol. Survey, Water resources of the United States. Paper presented to panel on water sponsored by Am. Soc. Civil Eng., New York, January 1950. Mimeographed by Geological Survey.

We have seen that ground water is not an independent resource but a part of the common water supply, and its use must always be considered in relation to the effect on surface supplies. Prior claims to water or riparian rights must be kept in mind in planning water-supply developments. Generally the decision as to the source or sources of supply to be utilized will be based on an economic study so that water of specified quality in desired quantity will be obtained at the least annual cost.

All possible sources of supply should be considered in preliminary cost analyses. Some of the factors to be considered are:

1. Distance from source to distribution or treatment point, and its effect on cost of pipe-line construction and pumping. It often is possible to obtain ground water from wells at the point desired, particularly if the desired quantity is small to moderate.

2. Temperature of water at source and point of use. Ground water is comparatively uniform in temperature and is cooler than surface water in the summer.

3. Cost of chemical treatment. Ground water generally is more highly mineralized than surface water in the same area but is more uniform in composition and is almost universally free of sediment. Ground-water reservoirs are inherently safer from contamination by industrial and organic wastes than are surface-water bodies.

4. Cost of reservoirs. Surface-water reservoirs require the construction of a dam and the acquisition of the flooded area. Use of ground-water reservoirs removes little or no land from other use, and usually the water is not subject to as great an evaporation loss as that in surface reservoirs. However, the operation of ground-water reservoirs generally is less efficient and more difficult than

that of surface-water reservoirs, and the seepage losses from ground-water reservoirs to surface streams or elsewhere may be considerable.

5. Effect of withdrawal on other supplies. Because of the close interrelationship of ground water and surface water, a withdrawal from one source usually reduces the supply available at another. A development that salvages natural waste in effect adds to the common supply, and in general ground-water supplies achieve this result more economically than do surface-water developments.

6. Effect of uncertainties in design on the cost. Factors of safety are necessary in any design, and the more uncertainty concerning any feature the larger the factor of safety necessary. Generally, in surface-water developments there are more data on the source (stream flow) and less uncertainty as to the available supply and storage than is the case in ground-water supplies. This tends to reduce the factor of safety required, and correspondingly reduces the total cost, for surface supplies. Adequate ground-water investigations will change this situation.

Use of Ground Water

For both ground and surface water the data on past and present uses and future requirements are woefully inadequate. At a time when use of water is increasing rapidly and is approaching the feasible limits of development in area after area, and when there is a growing national awareness of the true importance of water in our economy, we must admit that we do not even know how much we use, to say nothing of how much we have that can be used. Provision has never been made for a systematic national survey of our water uses and requirements, and only now has the Geological Survey been able to make a very small and inadequate start in that direction.

The data for use of ground water are a little better than those for surface water, principally because the industrial use of surface water is a largely unknown quantity. Guyton[/] estimated the use of ground water in

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[/] Guyton, W. F., U. S. Geol. Survey, Estimated use of ground water in the United States, 1945. Paper presented to Geol. Soc. Washington, Jan. 8, 1947; abstract published in Washington Acad. Sci. Jour., vol. 39, no. 3, pp. 105-106, Mar. 15, 1949. Full paper prepared for a committee of the Am. Soc. Civil Eng.; submitted to the Society for publication, also duplicated by the U. S. Geol. Survey, 1950.

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the United States in 1945 to be as follows:

	Billion gallons per day
Irrigation	10
Industrial (excluding water from municipal systems)	5
Municipal	3
Rural (excluding irrigation)	2
Total	20

Though more recent data as complete as those for 1945 have not yet been compiled, the use of ground water is known to have continued to increase. Guyton[/] estimates that the use for irrigation now may be about 15 billion

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[/] Guyton, W. F., U. S. Geol. Survey, Industrial use of ground water. Presented before Tech. Assoc. of the Pulp and Paper Industry, New York, Feb. 20, 1950. To be published in Tappi, journal of the Association.

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gallons per day, for something like 5 million acres. The other uses doubtless have increased also, but possibly not enough to change the order of magnitude of the figures given. The total current use, then, is estimated to be about 25 billion gallons per day. The figure could easily be in error by 10 to 25 percent.

The use of surface water for public supply is estimated rather reliably to have been about 9 billion gallons per day in 1945.[/] The current use

[/] Langbein, W. B., U. S. Geol. Survey, Municipal water use in the United States: Am. Water Works Assoc. Jour., vol. 41, no. 11, pp. 997-1001, November 1949. Data based on Inventory of water and sewage facilities in the United States (as of 1945), U. S. Public Health Service, 1948.

probably is larger, but how much is not known. The rural use, excluding irrigation, is not known but is believed to be a billion gallons per day or less. The use for irrigation is not known exactly, but probably about 4½ acre-feet per acre per year is taken from streams for some 20 million acres, or about 90 million acre-feet per year or about 80 billion gallons per day. A part of this water is lost by seepage from canals before it reaches the irrigated tracts, and that actually delivered to individual farmers or projects amounts to perhaps 3 acre-feet per acre. The water lost by seepage is available, in part, as "irrigation-return water."

The great unknown is industrial use of surface water. The largest use (excluding hydro-power use) is for steam-power generation and the quantity is uncertain. Various estimates have been made, based on the water requirement per ton of coal burned or kilowatt-hour of energy generated. Depending on what estimate is correct, the use for steam-power generation may range from 10 or 12 billion to more than 50 billion gallons per day but probably is somewhere near the middle of this range. A substantial part is salt or brackish water in tidal areas, so that the fresh-water requirement is correspondingly less. Requirements for other industrial uses are even more uncertain percentagewise, and the total industrial use of surface water may be anywhere between 30 or 40 and 100 billion gallons per day.

In the face of such uncertainty, obviously one of the first things we must do is to make a systematic survey of our water uses, area by area and use by use, to provide a basis for judging our future requirements.

It should be pointed out that the uses cited are gross, not net. In some places the same water is used over and over again, such as in the case of irrigation-return water in the West, the water used for industry from such rivers as the Mahoning in northeastern Ohio, and the water discharged from the sewage system of one city and reclaimed, in part, for the use of another city downstream. We have, therefore, another variable to consider in computing our net water requirements.

Following are tables from Guyton's paper "Estimated use of ground water in the United States, 1945," showing use of ground water by States, use in 53 areas of industrial and municipal pumping where the total draft is 20 million gallons per day or more, and uses by type of industry in 20 selected metropolitan areas where inventories have been made. Included also are the illustrations from that paper, comprising maps showing, by States, irrigation, industrial, municipal, rural, and total use of ground water in 1945, a map showing use in metropolitan areas, and a graph showing industrial use in the 20 selected metropolitan areas (figs. 10-16).

ESTIMATED USE OF GROUND WATER IN THE UNITED STATES, 1945
(million gallons per day)

State	Irrigation	Industrial	Municipal	Rural (excluding irrigation)	Total
Alabama	.....	80	55	30	165
Arizona	1,760	30	60	15	1,865
Arkansas	420	50	25	30	525
California	5,000	300	400	100	5,800
Colorado	400	25	20	25	470
Connecticut	.....	60	5	20	85
Delaware	.....	15	10	5	30
District of Columbia	.....	10	...	...	10
Florida	100	175	100	20	395
Georgia	.....	150	45	50	245
Idaho	125	10	25	20	180
Illinois	.....	265	115	60	440
Indiana	.....	350	100	45	495
Iowa	.....	150	100	75	325
Kansas	100	100	55	55	310
Kentucky	.....	100	20	40	160
Louisiana	380	250	50	30	710
Maine	.....	15	10	15	40
Maryland	.....	50	20	20	90
Massachusetts	.....	100	60	15	175
Michigan	5	165	100	50	320
Minnesota	.....	100	50	65	215
Mississippi	.....	25	35	35	95
Missouri	.....	130	40	45	215
Montana	25	15	10	25	75
Nebraska	450	35	85	80	650
Nevada	150	20	10	5	185
New Hampshire	.....	15	10	5	30
New Jersey	5	400	150	20	575
New Mexico	360	20	35	20	435
New York	25	310	250	70	655
North Carolina	5	40	20	50	115
North Dakota	.....	5	10	25	40
Ohio	.....	400	150	60	610
Oklahoma	10	15	30	35	90
Oregon	75	35	25	25	160
Pennsylvania	.....	250	135	90	475
Rhode Island	.....	20	10	5	35
South Carolina	5	20	15	25	65
South Dakota	5	15	20	35	75
Tennessee	.....	110	60	40	210
Texas	740	300	270	140	1,450
Utah	200	20	35	10	265
Vermont	.....	5	10	10	25
Virginia	.....	50	15	40	105
Washington	125	100	100	30	355

ESTIMATED USE OF GROUND WATER IN THE UNITED STATES, 1945--Continued
(million gallons per day)

State	Irrigation	Industrial	Municipal	Rural (excluding irrigation)	Total
West Virginia	.....	35	20	25	80
Wisconsin	.....	100	90	55	245
Wyoming	25	10	10	10	55
Total	10,495	5,050	3,075	1,800	20,420

ESTIMATED USE OF GROUND WATER IN AREAS WHERE LARGE AMOUNTS ARE USED FOR INDUSTRIAL OR MUNICIPAL PURPOSES, 1945
(million gallons per day)

Area	Total use	Industrial use	Municipal use
Los Angeles, Calif.	360 1/	60	80
Long Island, N. Y.	280 1/	100	150
Houston, Tex.	170	102	68
Memphis, Tenn.	105	74	31
San Antonio, Tex.	100 2/	15	38
East St. Louis, Ill.	89	85	4
Peoria, Ill.	85	66	19
(Philadelphia, Pa.- (Camden, N. J.	85	55	30
Dayton, Ohio	85 3/	50	35
Chicago, Ill.	84	48	36
Pittsburgh, Pa.	84 4/	68	16
Clinton, Ind.	80	80	..
Spokane, Wash.	67 1/	7	39
Baton Rouge, La.	63	59	4
Charlestown, Ind.	60	60	..
Kansas City, Mo.-Kans.	60	60	..
Kalamazoo, Mich.	52	44	8
Indianapolis, Ind.	48	45	3
Savannah, Ga.	47	32	15
St. Paul-Minneapolis, Minn.	47 5/	47	..
Cincinnati, Ohio	45	40	5
Louisville, Ky.	45	45	..
Phoenix, Ariz.	45	10	35
Des Moines, Iowa	44	24	20
Jacksonville, Fla.	41	22	19
Baltimore, Md.	40	40	..
Canton, Ohio	38	23	15
Brunswick, Ga.	37	37	..
Middlesex County, N. J.	37 6/	22	15
Miami, Fla.	45	11	34

1/ Includes use for irrigation.
2/ Includes uses for irrigation and recreation.
3/ Estimated for 1946 instead of 1945.
4/ Estimated for 1947 instead of 1945.
5/ Estimated for 1937 instead of 1945.
6/ Estimated for 1941 instead of 1945.

ESTIMATED USE OF GROUND WATER IN AREAS WHERE LARGE AMOUNTS ARE USED FOR INDUSTRIAL OR MUNICIPAL PURPOSES, 1945--Continued
(million gallons per day)

Area	Total use	Industrial use	Municipal use
Fernandina, Fla.	33	33	..
Terre Haute, Ind.	33	33	..
Middletown, Ohio	33	29	4
Mobile, Ala.	32	32	..
South Bend, Ind.	29	16	13
Columbus, Ohio	28	28	..
New Orleans, La.	27	27	..
Lake Charles, La.	27	25	2
Akron, Ohio	27	25	2
Milwaukee, Wis.	27	23	4
Rockford, Ill.	26	13	13
Sioux City, Iowa	25	18	7
Pensacola, Fla.	25	19	6
Binghamton, N. Y.	25	8	17
Wichita, Kans.	25	7	18
Las Vegas, Nev.	24 1/	8	12
Chillicothe, Ohio	22	21	1
El Paso, Tex.	21	11	10
Schenectady, N. Y.	20	6	14
Tacoma, Wash.	20	10	10
Boston, Mass.	20	7	13
Hamilton, Ohio	20	15	5
Massillon, Ohio	20	20	..
Total for 53 areas	3,046	1,865	859

1/ Includes use for irrigation.

USE OF GROUND WATER, BY TYPE OF INDUSTRY, IN 20 AREAS WHERE INVENTORIES HAVE BEEN MADE
(million gallons per day)

Type of industry	Chicago, Ill. 1945	Louisville, Ky. 1945	Minneapolis-St. Paul, Minn., 1937	Philadelphia, Pa. 1945	Kansas City, Kans. 1943
Oil refining	...	3.0	...	1.4	9.6
Paper manufacturing	...	...	...	...	...
Metal working	9.3	3.5	...	...	...
Chemical manufacturing	6.7	...	...	2.4	...
Building, air conditioning, and refrigerating	1.6	3.7	9.7	3.0	...
Distilling	...	9.2	...	12.0	...
Ice manufacturing and cold storage	...	2.6	3.3	2.7	3.1
Food processing	19.3	.6	.2	1.2	...
Rubber manufacturing	...	11.4	...	...	...
Meat packing	5.0	2.0	...	1.1	8.1
Brewing	...	3.1	10.2	...	...
Railroad yards	1.6	...	.6	1.5	.3
Gas and electricity	...	.8	...	3.0	...
Dairying	.5	2.2	4.3	1.1	...
Electric equipment manufacturing	...	...	...	...	...
Aircraft assembling	...	...	...	...	8.0
Resinous products manufacturing	...	...	...	...	...
Soap manufacturing	...	...	...	...	4.0
Laundering	.3	...	...	...	...
Glass manufacturing	...	...	...	...	...
Rope milling	...	...	...	2.0	...
Ship yards	...	...	...	...	...
Tobacco processing	...	.9	...	...	...
Miscellaneous	3.9	1.9	12.5	9.2	2.0
Total	48.2	44.9	40.8	40.6	35.1

USE OF GROUND WATER, BY TYPE OF INDUSTRY, IN 20 AREAS WHERE INVENTORIES HAVE BEEN MADE
(million gallons per day)

Type of industry	Houston, Tex. 1945	E. St. Louis, Ill. 1945	Pittsburgh, Pa. 1947	Peoria, Ill. 1945	Dayton, Ohio 1946
Oil refining	45.8	14.8	1.7	....	....
Paper manufacturing	18.1	....	1.5	1.0	11.5
Metal working	9.6	16.0	15.1	10.0	6.5
Chemical manufacturing	4.0	30.6	7.2	....	.9
Building, air conditioning, and refrigerating	1.7	.6	9.9	3.5	1.7
Distilling	....	....	....	26.0	....
Ice manufacturing and cold storage	4.4	....	6.2	....	2.2
Food processing	....	....	2.7	9.5	2.5
Rubber manufacturing	6.4	....	....	....	2.3
Meat packing	1.1	11.4	3.2	....	.3
Brewing	2.0	....	1.4	1.2	.5
Railroad yards	2.5	6.2	6.0	....	.3
Gas and electricity	2.1	....	6.8	....	5.7
Dairying	....	.2	2.0	.5	.8
Electric equipment manufacturing	....	....	....	....	10.4
Aircraft assembling	....	....	....	....	....
Resinous products manufacturing	....	....	....	....	....
Soap manufacturing	....	....	....	....	.3
Laundering	.8	....	....	.3	.6
Glass manufacturing	....	....	2.3	....	....
Rope milling	....	....	....	....	....
Ship yards	1.2	....	....	....	....
Tobacco processing	....	....	....	....	....
Miscellaneous	2.2	5.5	1.8	14.0	3.5
Total	101.9	85.3	67.8	66.0	50.0

USE OF GROUND WATER, BY TYPE OF INDUSTRY, IN 20 AREAS WHERE INVENTORIES HAVE BEEN MADE
(million gallons per day)

Type of industry	Mobile, Ala. 1945	Akron, Ohio 1944	Jacksonville, Fla. 1945	Chillicothe, Ohio 1945	Pensacola, Fla. 1945	South Bend, Ind. 1945
Oil refining	....	....	....	....	....	....
Paper manufacturing	15.0	2.0	4.1	20.0	8.2	....
Metal working	....	.4	....	....	....	7.2
Chemical manufacturing	....	5.0	....	....	....	....
Building, air conditioning and refrigerating	11.0	....	2.7	....	....	2.3
Distilling	....	....	....	....	....	....
Ice manufacturing and cold storage	....	....	8.2	....	....	.7
Food processing	....	....	....	....	....	....
Rubber manufacturing	....	16.0	....	....	....	....
Meat packing	....	.3	....	....	....	....
Brewing	....	....	.5	....	....	1.6
Railroad yards	....	....	1.4	....	....	.8
Gas and electricity	....	....	.8	....	....	....
Dairying	....	.8	....	....	....	.3
Electric equipment manufacturing	....	....	....	....	....	....
Aircraft assembling	....	....	....	....	....	....
Resinous products manufacturing	....	....	....	....	8.2	....
Soap manufacturing	....	....	....	....	....	....
Laundering	....	....	....	....	....	.3
Glass manufacturing	....	....	....	....	....	....
Rope milling	....	....	....	....	....	....
Ship yards	....	....	....	....	....	....
Tobacco processing	....	....	....	....	....	....
Miscellaneous	6.0	.5	4.1	1.0	2.7	2.5
Total	32.0	25.0	21.8	21.0	19.1	15.7

USE OF GROUND WATER, BY TYPE OF INDUSTRY, IN 20 AREAS WHERE INVENTORIES HAVE BEEN MADE
(million gallons per day)

Type of industry	Milwaukee, Wis. 1944	Miami, Fla. 1945	El Dorado, Ark. 1945	Oklahoma City, Okla. 1945	Total	Number of areas
Oil refining	....	....	6.2	1.0	83.5	8
Paper manufacturing	....	....	....	....	81.4	9
Metal working	3.2	....	....	....	80.8	10
Chemical manufacturing	....	....	3.1	....	59.9	8
Building, air conditioning and refrigerating	2.3	1.6	....	.6	55.9	15
Distilling	....	....	....	....	47.2	3
Ice manufacturing and cold storage	....	4.7	....	.7	38.8	11
Food processing	1.2	....	....	....	37.2	8
Rubber manufacturing	....	....	....	....	36.1	4
Meat packing	1.1	....	....	1.0	34.6	11
Brewing	4.1	....	....	.3	24.9	10
Railroad yards	....	....	....	.2	21.4	11
Gas and electricity	....	1.2	....	....	20.4	7
Dairying	....	2.2	....	....	14.9	11
Electric equipment manufacturing	....	....	....	....	10.4	1
Aircraft assembling	....	....	....	.5	8.5	2
Resinous products manufacturing	....	....	....	....	8.2	1
Soap manufacturing	....	....	....	....	4.3	2
Laundering	....	....	....	.2	2.5	6
Glass manufacturing	....	....	....	....	2.3	1
Rope milling	....	....	....	....	2.0	1
Ship yards	....	....	....	....	1.2	1
Tobacco processing	....	....	....	....	.9	1
Miscellaneous	3.0	1.4	....	.1	77.8	19
Total	14.9	11.1	9.3	4.6	755.1	20

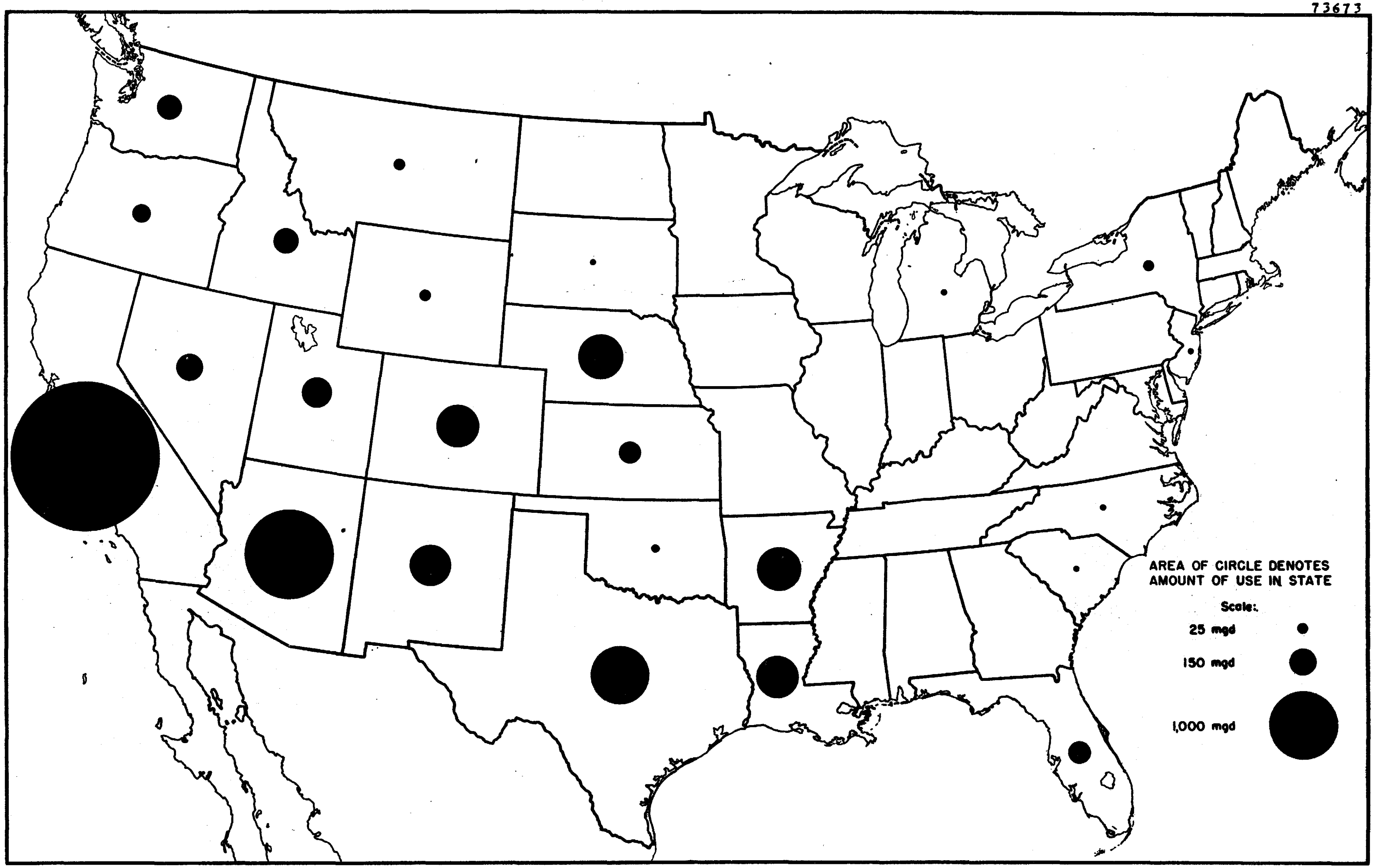

FIGURE 10— USE OF GROUND WATER FOR IRRIGATION – 1945

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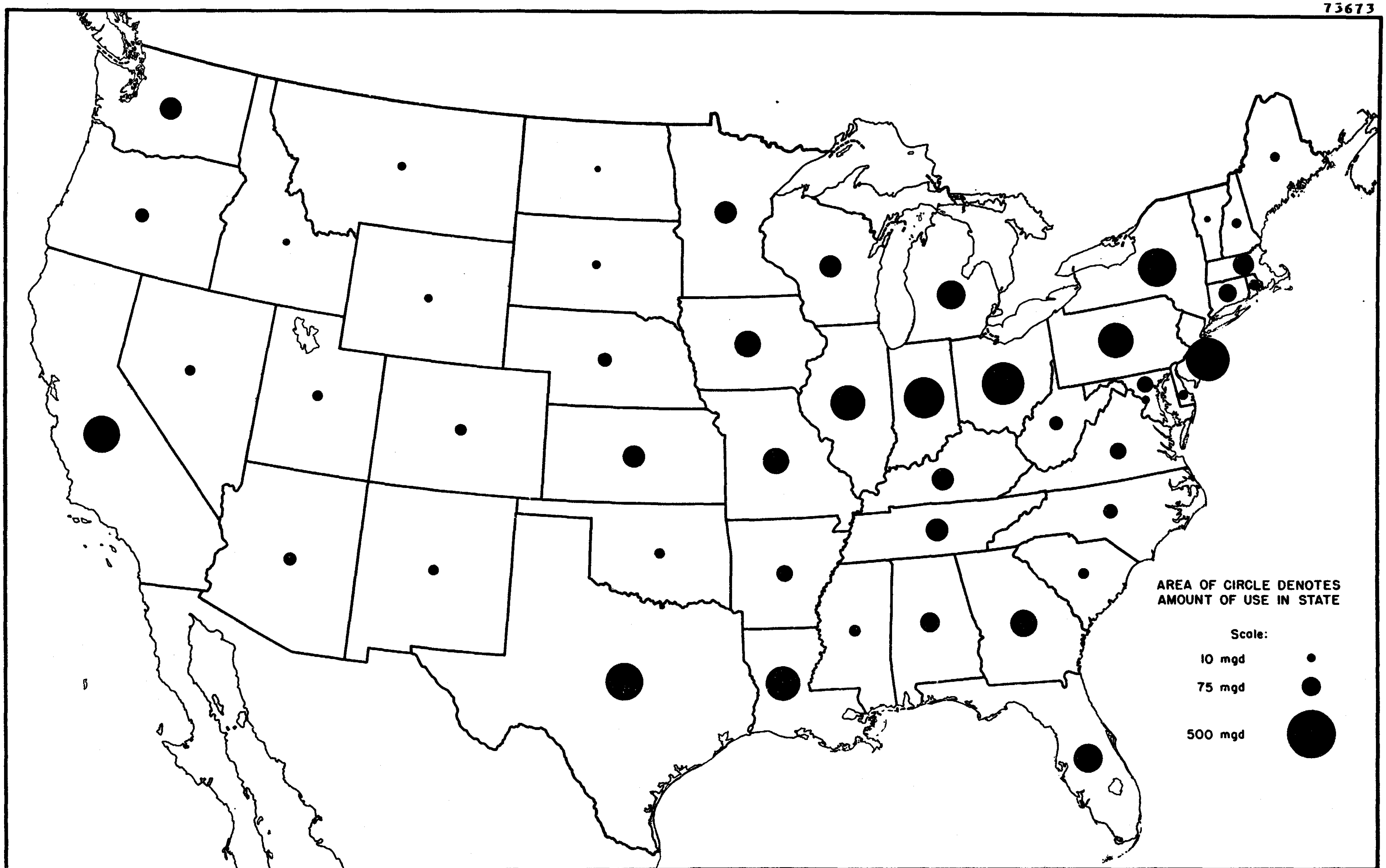

FIGURE 11 — INDUSTRIAL USE OF GROUND WATER — 1945
(not including water supplied from municipal systems)

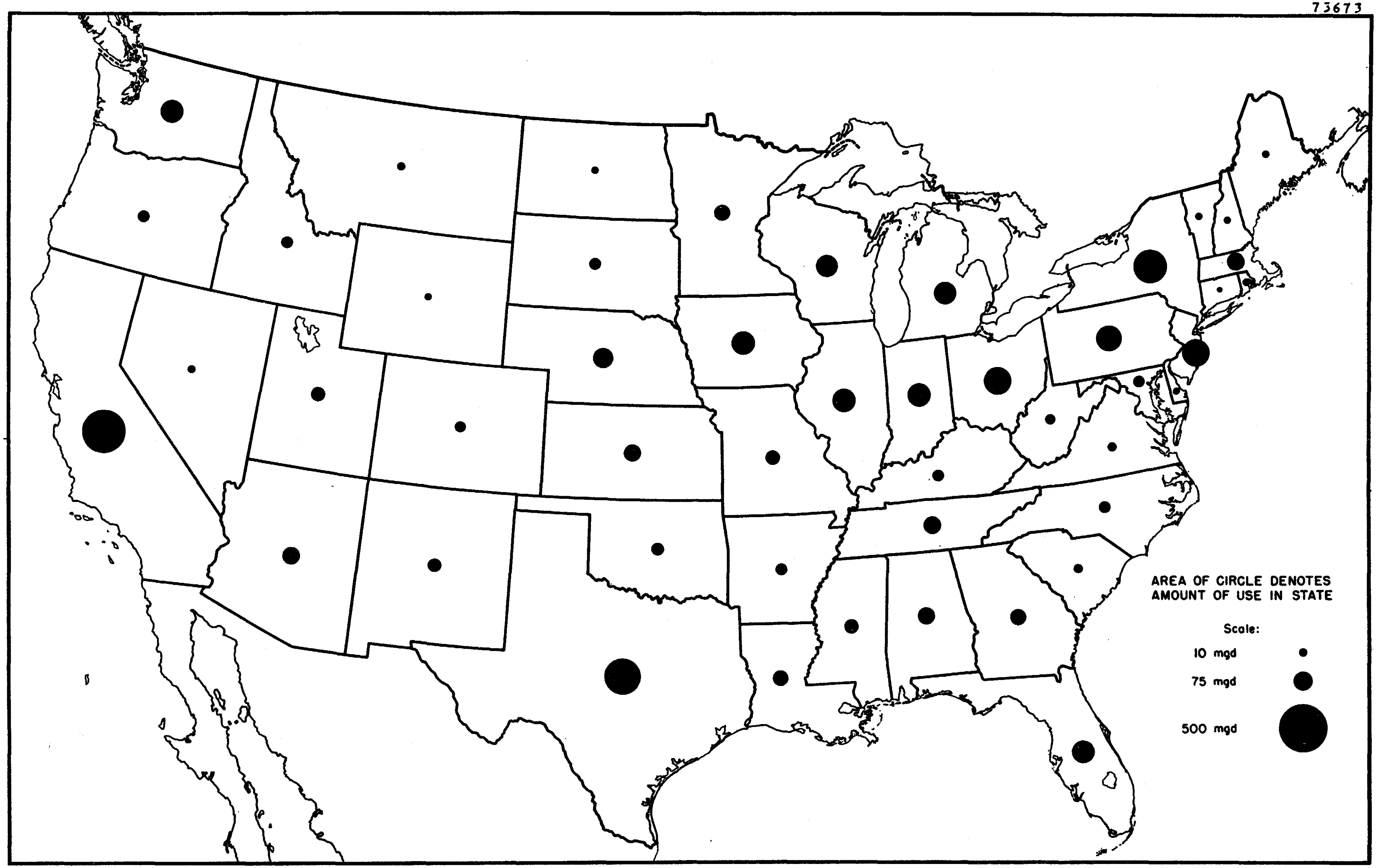

FIGURE 12 — MUNICIPAL USE OF GROUND WATER — 1945

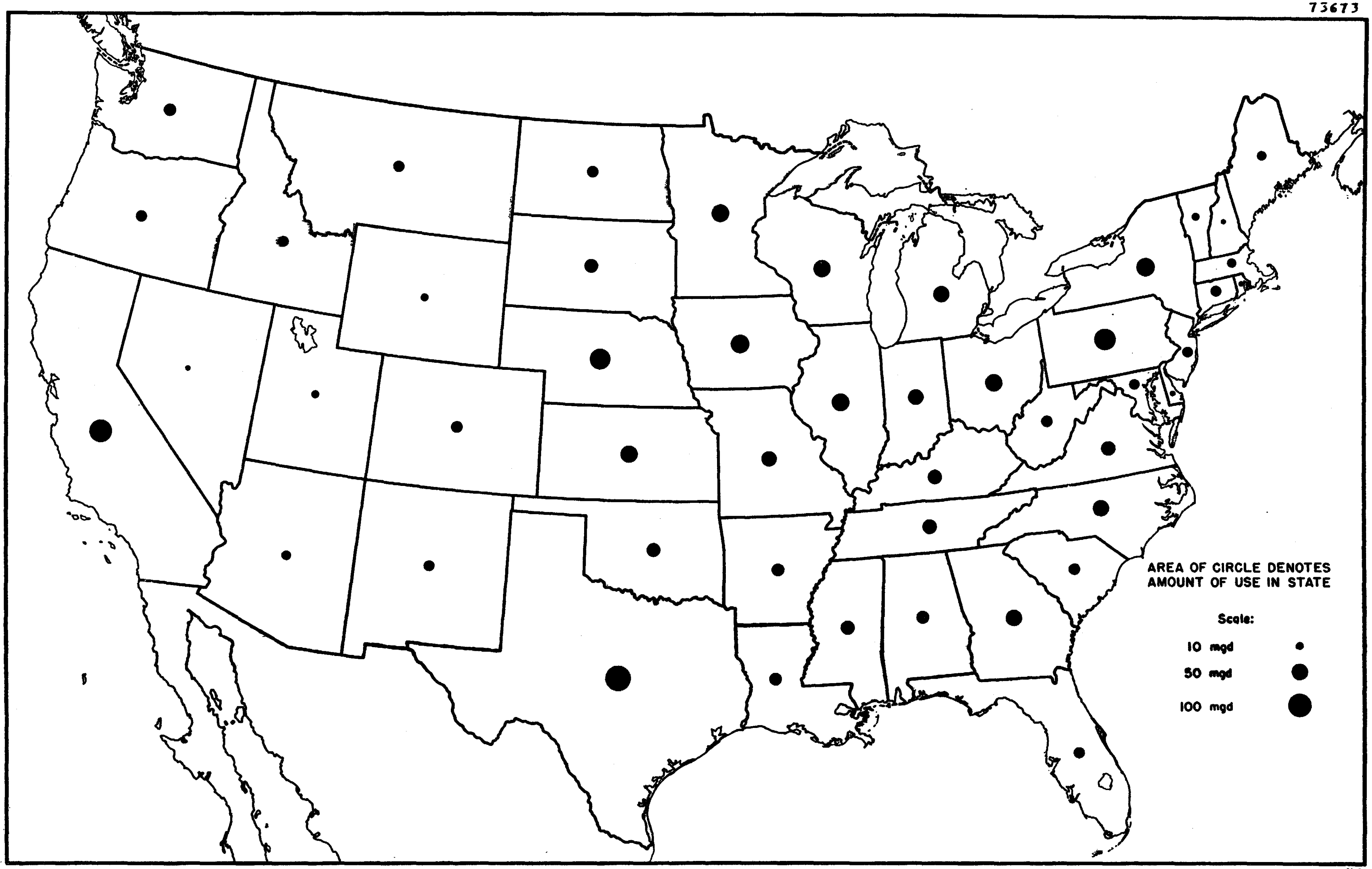

FIGURE 13 — RURAL USE OF GROUND WATER — 1945
(not including use for irrigation)

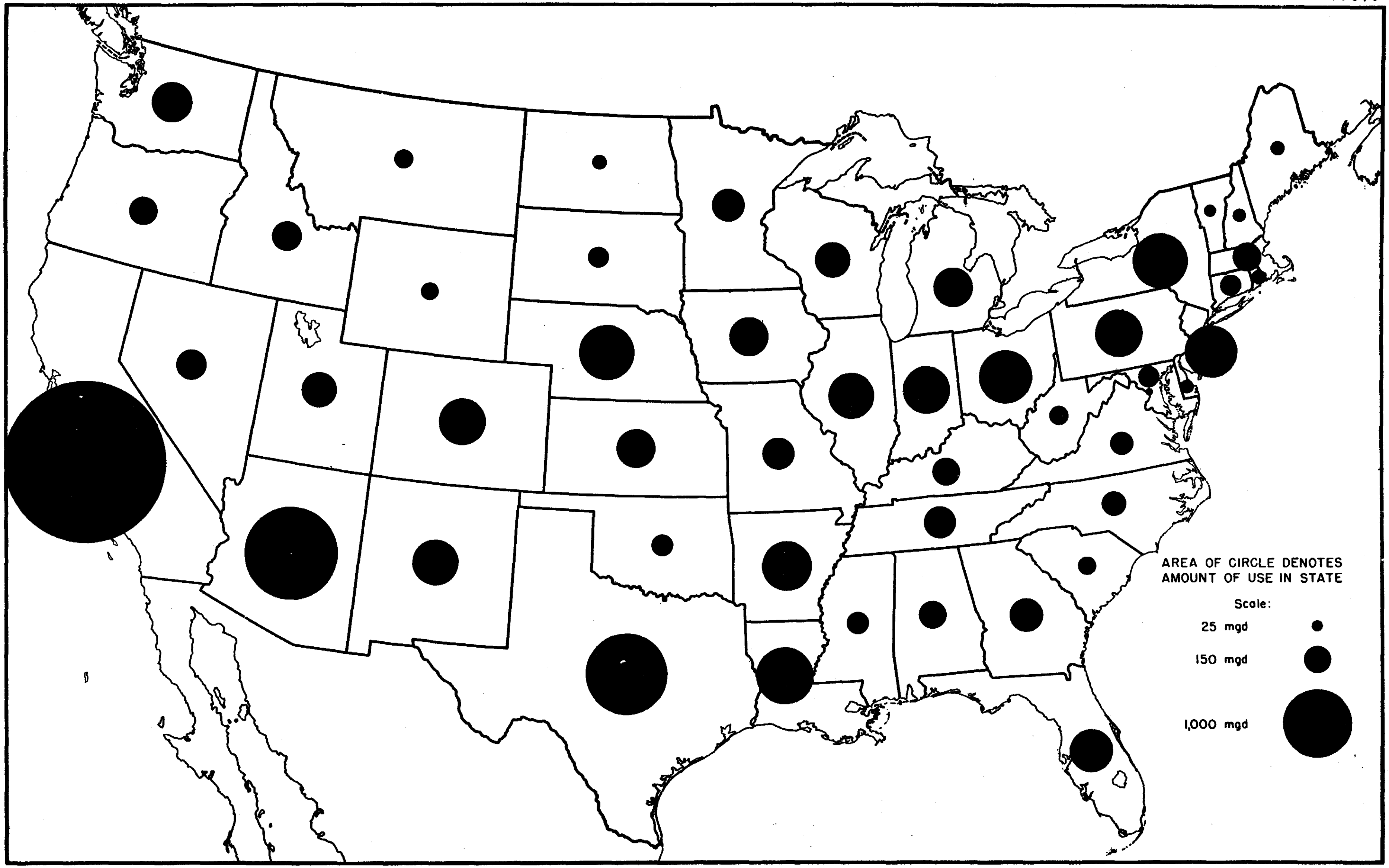

FIGURE 14 — TOTAL USE OF GROUND WATER — 1945

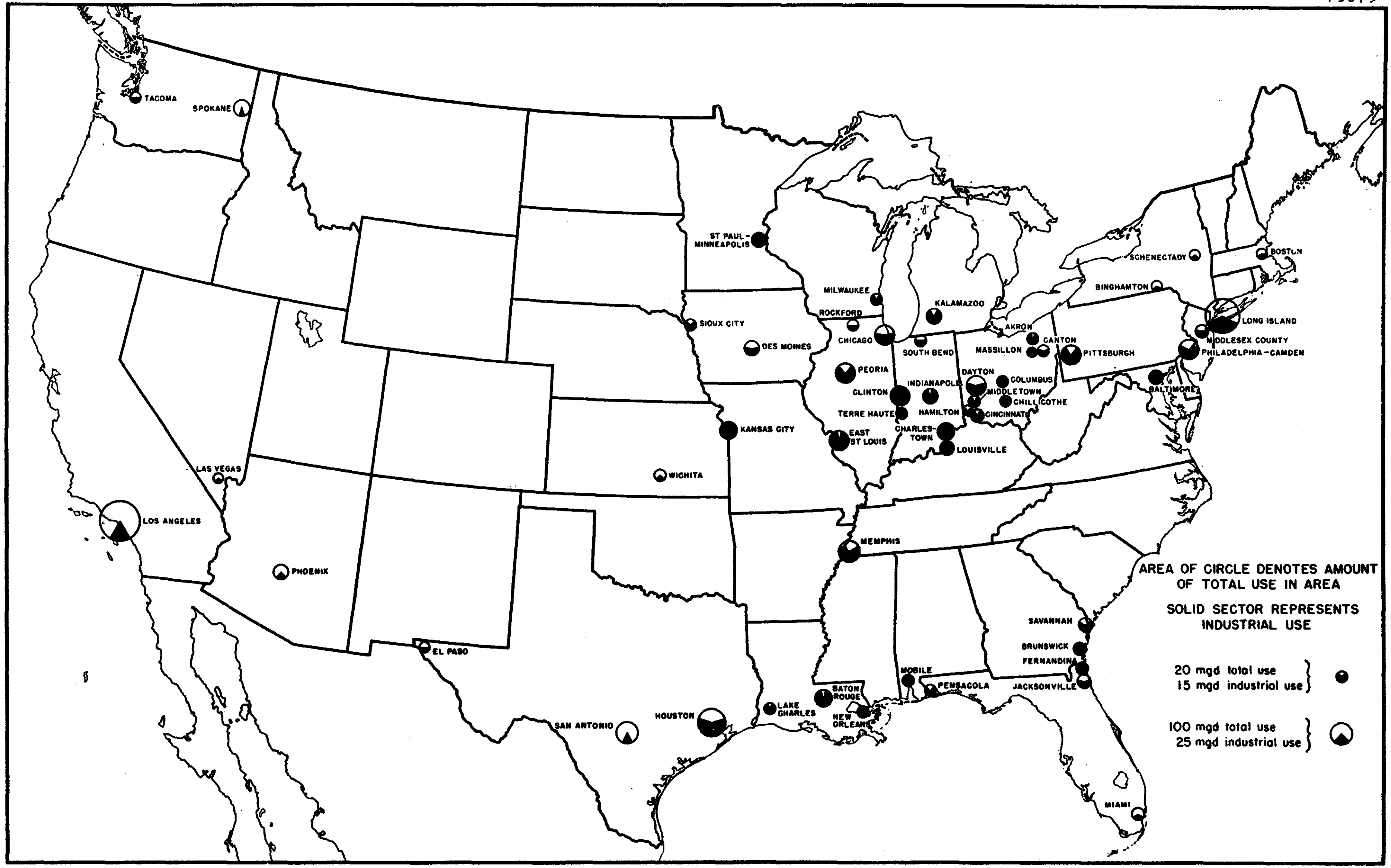

FIGURE 15 — USE OF GROUND WATER IN METROPOLITAN AREAS — 1945
(only areas with 20 mgd or more total use are included)

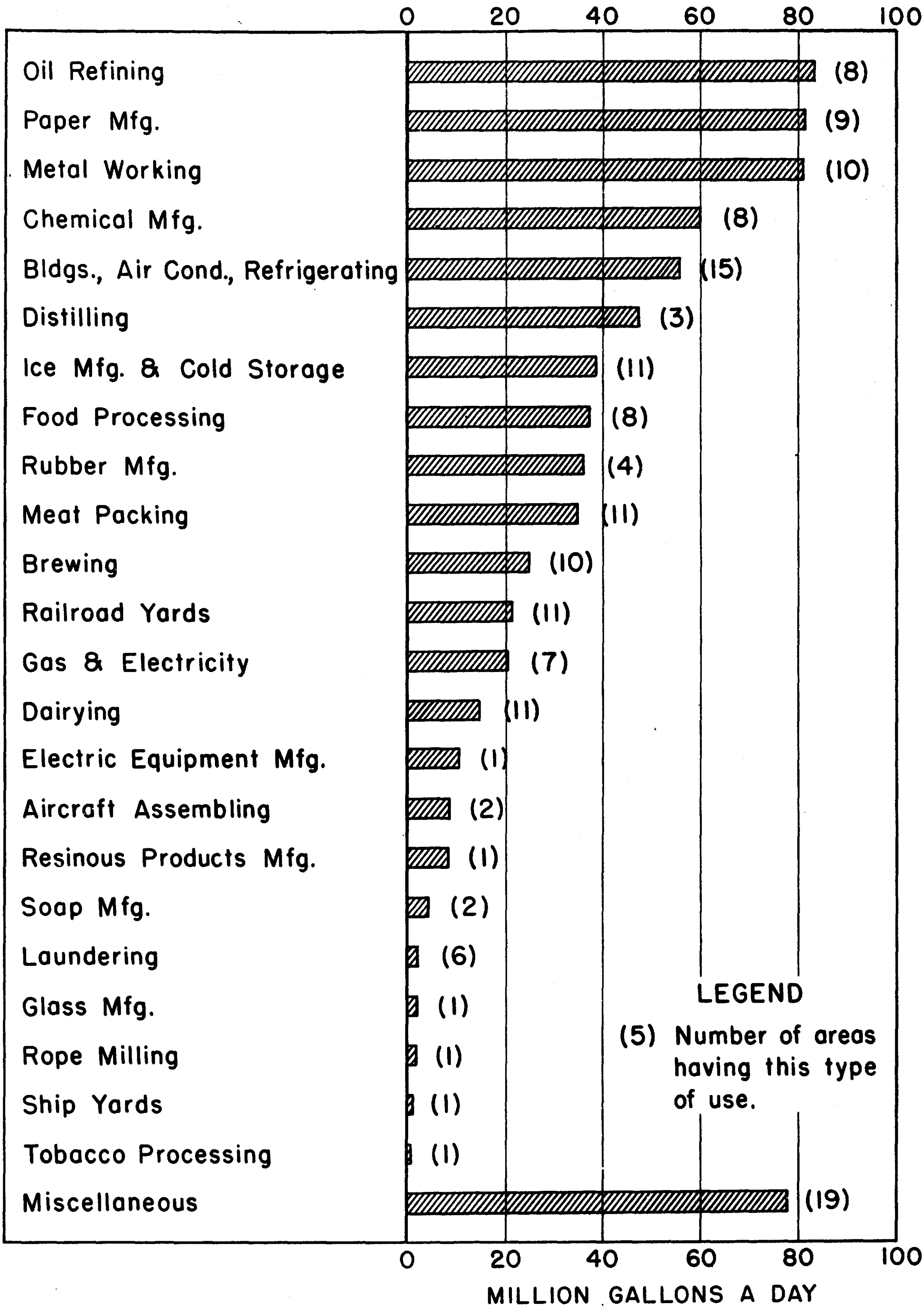

FIGURE 16 — USE OF GROUND WATER BY INDUSTRIES IN 20 SELECTED METROPOLITAN AREAS.
(Not including water from municipal supplies)

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It is estimated roughly that the use of ground water in the United States approximately doubled from 1935 to 1945--from about 10 to about 20 billion gallons per day, and as stated above, it is now in the neighborhood of 25 billion gallons per day. It meets now from perhaps a fifth to an eighth of our total water requirements; in the future the use of ground water and perhaps its proportion of the total water use will increase. It is up to us, then, to learn more reliably how much water we need and are likely to need, and to find it, always considering the availability and cost of both surface water and ground water and the relation between them in each area and basin.

THE CURRENT SITUATION

We have laid the background for an understanding of the occurrence of water in nature and as affected by use, with special reference to ground water. Let us now consider the general water-resources conditions in the United States, again with special reference to ground water but with recognition of the intimate relation between ground and surface water. It is not possible in a single report to give a comprehensive picture. We have only a small part of the information, and even if we had it all some hundreds of thousands of pages would be required to set it down. We can, however, present a general picture and call attention to some of the more important problems, possible solutions, and potential sources of water.

Water has always been an important factor in the settlement and development of our country. Cities and farms were located where favorable conditions existed, and water was always one of the principal determining factors, for domestic use, transportation, industrial use and power generation, and irrigation. In many places, however, factors other than water, such as soil, climate, strategic location on trade routes, and availability of raw materials, have resulted in the development of areas beyond the ability of the local water resources to keep up with the demand. As a result, and in too many cases because of lack of foresight, once-plentiful water supplies have become inadequate, and such problems will become progressively more numerous and serious until we give water its rightful place in our thinking.

The water supplies are most inadequate and the problems most serious in the arid West, where there never has been and perhaps never will be enough water for full development of the great agricultural and industrial potential. The relatively well watered East has numerous but so far less serious problems; enormous supplies remain for development and they can be made still larger and more secure by reducing the widespread pollution of our streams.

The general features of the four principal regions of the United States and a few of the most important water problems are described in the following sections.

Figure 17 is a map of the United States showing areas in which individual wells generally are capable of yielding at least 50 gallons per minute of water containing not more than 2,000 parts per million of dissolved solids (the map includes some areas where more highly mineralized water is actually used successfully). Five types of areas are shown: those with unconsolidated aquifers, those with consolidated-rock aquifers, those with both, those alluvium-filled valleys or "watercourses" where perennial streams recharge or can be made to recharge the alluvium, and similar valleys not now occupied by perennial streams.

Figure 17 is based on a map prepared for the Conservation Foundation, New York, N. Y. The Foundation is making a survey of the ground-water conditions and problems of the United States; the map is to form a part of the Foundation's report, which will be a broad treatment of the ground-water situation as a basis for its evaluation in relation to other national problems. The map was compiled by Dr. H. E. Thomas, district geologist of the Geological Survey, Salt Lake City, who was on leave from the Survey and was in charge of the Foundation's ground-water study. It is based on data furnished by the field offices of the Geological Survey and by other Federal and State agencies. It varies in accuracy in accordance with the comprehensiveness of the available data for the different parts of the country. For some large areas for which ground-water data are scanty the map must be considered only tentative; it is subject to revision throughout as additional data are obtained.

Atlantic and Gulf Coastal Plains

The Atlantic and Gulf Coastal Plains begin at the northeast with the group of sandy islands and capes including Long Island, Cape Cod, Marthas Vineyard, and Nantucket Island and extend south and west to include the southeastern half of Texas. The region includes the Mississippi Embayment, which extends up to Cairo, Ill., and includes the corners of Missouri and Kentucky. The region is prevailingly humid, except for the subhumid to semiarid western part of the Texas section of the region. The climate is generally warmer than that of the east-central region, however, and the evaporation is higher though it is exceeded by the precipitation in much of the region except the southwestern part. The average runoff is mostly around 20 inches in New Jersey and the adjacent area and 20 to 30 inches in southern Alabama and Mississippi. It is generally 10 to 20 inches in the rest of the region as far west as east-central Texas, whence it drops off to the west to an inch or less.

The region is underlain by coastward-dipping strata of sand, clay, marl, and limestone. The total thickness ranges from a feather edge at the inner border of Fall Line, where the underlying hard rocks come to the surface, to many thousands of feet in the extreme south. Except for the limestones of Florida and the adjacent area in Georgia and South Carolina and those of the Edwards Plateau in Texas, the rocks are largely unconsolidated. The limestones and sands of the Coastal Plain constitute some of the most extensive and productive aquifers of the United States. Because of the favorable structure of coastward-dipping permeable sand and limestone beds alternating

Base compiled by U. S. Geological Survey
Projection and shore line by the U. S. Coast and Geodetic Survey
Albers equal-area projection
North American datum

Figure 17. GROUND-WATER AREAS IN THE U. S.

with tight clays and marls, artesian conditions prevail throughout the region except in the beds near the surface. Flowing wells can be obtained almost everywhere along the coast and in the deeper valleys extending back from it. The water of the limestones is hard but in much of the region that in the sands some distance down the dip has been softened naturally by base exchange (exchange of sodium in the sediments for the hardness-producing calcium and magnesium picked up by the water in the recharge areas). On the whole, the Coastal Plain is perhaps the most productive ground-water region in the United States, _/ though in some areas incomplete flushing of the salt water

_/ Stringfield, V. T., U. S. Geol. Survey, Artesian water in the Southeastern States. Paper prepared for symposium on mineral resources of Southeastern States, held at the University of Kentucky, March 1950, and to be published by the University.

that once saturated the beds makes it difficult to obtain good water. The Tamiami limestone of southeastern Florida is the most permeable aquifer ever investigated in detail by the Geological Survey. Its transmissibility averages several million gallons a day per foot, in comparison with transmissibilities in the general range of 50,000 to 500,000 for some of the productive aquifers in other parts of the country. The Floridan aquifer, comprising the Ocala limestone and associated limestones of northern Florida, southern Georgia, and southeastern South Carolina, supplies some of the largest springs and flowing and pumped wells in the country. The Edwards limestone of Texas supplies the largest known flowing well in the world at San Antonio, yielding nearly 25 million gallons a day.

The water supply of the region is large, but there are numerous problems.

Middlesex County, N. J., is heavily pumped and about fully developed, but much ground water remains untouched in the southern half of the State. In the Philadelphia - Camden area there is local overpumping, and contamination of the ground water by polluted water from the Delaware River. The area presents an interstate problem that can be solved through cooperation such as that providing for development of the Delaware River.

The Baltimore area is heavily pumped and there is a salt-water-contamination problem. The Washington, D. C., area is not heavily pumped but ground water is hard to get in some places where it is needed for domestic and industrial use and public supply for suburban housing developments. Southeastern Virginia and northeastern North Carolina are characterized by limited supplies of good ground water, though brackish water is abundant. The Savannah area, Ga., is overpumped so far as long-term salt-water encroachment is concerned, but encroachment is many years away, additional ground water is available to the west, and the city has developed a supply from the Savannah River.

Ground water of good quality is scarce in the Everglades area and extreme coastal area of southern Florida, and locally along the coast elsewhere, but on the whole Florida and adjacent areas in Georgia and South Carolina form one of the most productive ground-water areas in the country.

Heavy pumping has caused local encroachment of salty water at Mobile, Ala., and Texas City, Tex., and may be causing it in the rice-irrigation area of southwestern Louisiana. Ground water is naturally brackish in the New Orleans area and in much of the southern Texas coastal area. The Grand Prairie region in eastern Arkansas is overdeveloped. The Memphis, Baton Rouge, and Houston areas, among others, are very heavily pumped and there may be some over-development in parts of the latter two areas.

On the whole, however, ground-water problems in the Coastal Plain are local, and tremendous supplies await development in most parts of the region.

Surface water is abundant throughout most of the Coastal Plain. There are numerous problems of flooding because of the low gradients of the streams, and problems of erosion in the higher areas and contribution of silt to the streams, organic and chemical pollution from sources both upstream and within the region, salt-water encroachment in the tidal portions of the streams during periods of low flow, and inadequate surface storage to provide increased low flow, protection against floods, and dilution of the pollution load. On the whole, however, with adequate investigation to determine the ground-water potential and stream-flow characteristics, intelligent development of ground and surface water, and reduction of pollution, floods, and soil erosion, the Coastal Plain will have ample water of good quality for the indefinite future.

East-Central Region

The east-central region can be defined as the part of the United States east of the Great Plains and north and west of the Atlantic and Gulf Coastal Plains. The climate is generally humid. The precipitation decreases from south to north, but so does the temperature and with it the "potential evaporation" or amount of water needed to meet evapo-transpiration demands. Precipitation generally exceeds potential evaporation, except in the western part. The runoff is relatively high, though it decreases from east to west. It is 20 inches or more in the mountains and in most of New England, New York, and Pennsylvania, and 10 to 15 inches in much of the area to the west as far as the Mississippi River, and in Missouri and Arkansas beyond. It then falls off rapidly to half an inch to a couple of inches at the edge of the Great Plains.[/]

[/] Langbein, W. B., and others, Annual runoff in the United States: U. S. Geol. Survey Circ. 52, pl. 1, June 1949.

The region is underlain by consolidated rocks - crystalline rocks in New England, the Adirondacks, the Blue Ridge and Piedmont, and northern Wisconsin and Minnesota; and folded or flat-lying sedimentary rocks elsewhere. These rocks are prevailingly of low or moderate permeability, and at depth they generally contain little water or water of poor quality. The principal exceptions are deep-lying fresh-water-bearing sandstones in Iowa, Illinois, and Wisconsin and some of the limestones of the Appalachian Valley and Ridge Province and the Ozark region. From the limestones of the Ozarks issue some of the largest springs in the United States, but the water travels principally in large solution channels that are difficult to locate in drilling wells, so that as sources of well water they are not especially important.

Throughout New England and New York, in northern Pennsylvania, and farther west in the area generally north of the Ohio and Missouri Rivers, the bedrocks are covered by glacial drift ranging widely in thickness and permeability. It is thickest and most permeable in Michigan and northern Indiana, but in all except the extreme western part of the region it contains coarse deposits of glacial outwash gravel; also, the valleys of the Ohio, Missouri, and Mississippi Rivers and their principal tributaries contain thick and productive glacial gravels from which large supplies can be developed by "induced infiltration." In western Minnesota and the eastern Dakotas the unconsolidated mantle consists mostly of clayey lake beds or glacial drift derived from the soft shale bedrock, and stringers of sand and gravel are few and far between.

In southern Indiana, southern and western Illinois, northern Missouri, and part of Iowa the glacial drift is thin and not especially productive. In these areas and also to the south the bedrocks are the principal or only source of ground water, and with the exceptions noted above they are not highly productive. Domestic supplies are available generally, however, though even these supplies are meager in such areas as the Bluegrass region of Kentucky[/]

[/] Hamilton, D. K., Areas and principles of ground-water occurrence in the inner Bluegrass region, Ky: Kentucky Geol. Survey Bulletin, in course of publication. Prepared in cooperation with U. S. Geol. Survey.

and the Pennyroyal country of southern Kentucky and northern Tennessee. In the last-named area the drainage is largely underground through cavernous limestone, but it takes place so quickly that only small year-round supplies are available. Ground water is difficult to obtain in the uplands of much of eastern Kansas and in Oklahoma east of the Panhandle, but river alluvium and terrace gravels yield small to moderate supplies in many places.

New England's present water problems fortunately are minor in comparison to those of some other parts of the country. On the average there is a surplus of precipitation over evaporation, and the runoff is high and rather well sustained because of the uniformity of precipitation during the year and the blanket of glacial drift and weathered bedrock. Total water use is not heavy except for power production, and large additional supplies are available from productive watersheds and from permeable glacial gravels in many valleys. The chief problems in the past have been caused by floods, droughts, and stream pollution. All have been under vigorous attack in recent years and the situation has improved and is continuing to do so. Reservoirs have been built to provide flood control and increased low-water flow. The increased flow, and steps taken under the New England Interstate Water Pollution Control Compact, are helping to reduce stream pollution. Domestic users of ground water are turning from shallow dug wells, readily depleted by drought, to more reliable deeper drilled wells.

New York State has an abundant water supply but more serious problems of water shortage due to heavy and increasing use, and a higher degree of stream pollution in the densely populated areas. The current New York City water shortage has sparked the recent greatly increased national interest in water. It is serious now but will be ameliorated by construction now under way, after a period of considerable discomfort and inconvenience. In the meantime it will have served as an excellent example and warning to other water users that "it can happen here," and eventually it may prove to be a blessing in disguise.

Pennsylvania has a few serious problems, including heavy stream pollution and local overpumping of ground water at Pittsburgh and contamination of ground water by polluted Delaware River water at Philadelphia (in the Coastal Plain). The stream-pollution problem is under vigorous attack by the State.

The Piedmont and Blue Ridge provinces extending from Pennsylvania to Alabama make up an area of generally ample but widely polluted surface water and generally small ground-water supplies, which, however, meet the needs of rural users, most small towns, and many industries. Adequate flood, sedimentation, and pollution-control measures will make the surface-water supply adequate and safe, and there is a promise that ground-water research will make possible more successful location of productive wells. Moderate to large supplies, hitherto almost untouched, can be developed by induced infiltration in the thin alluvium of the river valleys.

The Appalachian Valley and Ridge province west of the Blue Ridge has large surface- and ground-water supplies but considerable pollution of the streams, and also of the ground water because much of it occurs in cavernous limestone. There are difficult problems of mine drainage, and much research is needed on the occurrence of ground water.

The Appalachian Plateaus and Interior Low Plateaus extending from western Pennsylvania through West Virginia and southeastern Ohio southward to Alabama and west to the Mississippi River form a region of variable water supply. The rocks are of low average permeability, with some marked exceptions such as the alluvium of the Ohio River and its larger tributaries and the limestones of the Tennessee Valley, and the plateaus are well dissected by streams, so that runoff is flashy and there are problems of both floods and deficient low flow. There is serious pollution of the Ohio River and its tributaries by sewage and industrial wastes and of smaller streams by acid water draining from coal mines. More adequate storage of surface water would go far to solve all these problems.

The Great Lakes States have an abundant water supply but numerous local problems of inadequate water-supply facilities to meet increasing demands, and pollution of streams and of the Great Lakes themselves at the larger cities. Stream flow is well to poorly sustained, depending on the local thickness and permeability of the glacial drift that blankets most of the area.

Greatly increased development of ground water is possible in many parts of the area, particularly northern Indiana and the Lower Peninsula of Michigan. Possibly the outstanding ground-water problem is that in northeastern Illinois but there are many others. Increased use of ground water in areas now lightly pumped and provision of more adequate surface storage for dry-season water supply and flood and pollution control may be expected to meet the mounting water demands of the area, though good reservoir sites are scarce because of the flatness of the terrain.

The Great Lakes themselves are a large and obvious source of water. Though dependable data on precipitation on and evaporation from the lakes are meager, it is apparent that, on the average, precipitation exceeds evaporation. This excess and the water from tributary streams add up to a total natural discharge into the St. Lawrence River averaging 226,000 cubic feet per second.[1] Even the large diversions for power and other uses

[1] U. S. Geol. Survey Circ. 44, Large rivers of the United States, p. 5, May 1949.

reduce the flow over Niagara Falls by only 50,000 to 60,000 cubic feet per second, and of course the water diverted for power at the falls returns to the Niagara River below the falls. Navigation requirements preclude excessive lowering of the lakes and diversion of water from the lakes must be governed by international agreements, but even so, large additional use would be feasible, as most of the water would return to the lakes. Control of pollution, especially in the highly industrialized areas in Ohio, Indiana, Illinois, and Michigan, is one of the principal problems, for both present and possible future uses.

The part of the region between the belt surrounding the Great Lakes and the belt just east of the Great Plains has somewhat similar problems. It includes Iowa, Missouri, southeastern Oklahoma, and northwestern Arkansas. Surface water is generally abundant but storage is needed to even out the cycle of floods and low-flow deficiency. Large ground-water supplies are restricted mainly to the valleys of the principal streams, and to scattered areas of permeable bedrock like that supplying the springs of the Ozarks. There are numerous problems of chemical and organic pollution and heavy silt loads in streams. Additional surface storage and prospecting for and development of untapped ground water are called for.

The belt just east of the Great Plains is one of generally deficient water supply, with considerable oversupply at times in the form of floods. The rock formations are generally of rather low permeability and both total and low-water runoff are less than in the more humid areas to the east. The Missouri Basin development is a coordinated program to provide more water for the northern part of the belt. Regulation of the Arkansas and Red Rivers and their tributaries would do the same for the southern. There are serious problems of chemical pollution, both man-made and natural, especially in the southern part, and heavy silt loads in nearly all streams throughout the belt. One of the principal ground-water problems, calling for interstate cooperation and careful planning of withdrawals, is that of the Tri-State area in southeastern Kansas, northeastern Oklahoma, and southwestern Missouri. Ample surface water can be developed in that area, but not always at small cost to towns and industries distant from the larger streams.

Great Plains Region

The Great Plains region includes the part of the country, east of the Rocky Mountains, extending from eastern Montana to south-central Texas and including western North Dakota, most of South Dakota and Nebraska, western Kansas and Texas, the Oklahoma Panhandle, and eastern New Mexico. It is an elevated east-sloping prevailingly semiarid plain or plateau. Potential evaporation exceeds precipitation in practically the whole region, so that if the precipitation were distributed evenly there would be little surface runoff or ground-water recharge. The runoff is mostly an inch or less except in the sand-hills region of Nebraska, where the sands absorb precipitation very readily and pay it out slowly around the margins of an area of several thousand square miles, so that the runoff is 2.5 to 5 inches.

The region is underlain by gently dipping stratified sedimentary rocks, mostly sandstone and shale and some limestone. The sandstones are the principal water bearers in these bedrock formations. They are of low permeability and yield in comparison to more productive aquifers elsewhere, but they supply thousands of domestic, stock, and public-supply wells in parts of the region where better aquifers are not present. The Dakota sandstone, which underlies most of the region, forms one of the largest artesian reservoirs in the world. Though the sandstone is not very permeable, its water was originally under high pressure because of the high altitude of its outcrop areas in the foot-hills of the Rockies and the Black Hills and of the presence above it of a thick, tight confining bed of shale. Many of the wells when drilled had pressures of more than 100 pounds per square inch (230 feet of water) at the surface and flows of several hundred gallons per minute._/ The highest re-

_/ Wenzel, L. K., and Sand, H. H., Water supply of the Dakota sandstone in the Ellendale-Jamestown area, N. Dak.: U. S. Geol. Survey Water-Supply Paper 889-A, p. 5, 1942. Prepared in cooperation with North Dakota Geol. Survey.

ported pressure was 250 pounds per square inch (575 feet of water), possibly somewhat in error. A well at Redfield, S. Dak., had a pressure of 177 pounds per square inch (410 feet of water)./ The highest reported yield by natural

/ Op. cit.

flow was 4,350 gallons per minute from a well at Chamberlain, S. Dak./

/ Darton, N. H., Preliminary report on artesian waters of a portion of the Dakotas, in U. S. Geol. Survey 17th Ann. Rept., pt. 2, p. 609, 1896.

The bulk of the water was derived from artesian storage, however, and the head was dissipated rapidly in a large region, particularly the Dakotas. Now many wells have ceased to flow and most of the remaining ones flow only a few gallons per minute, as in the Ellendale-Jamestown area, N. Dak./

/ Wenzel, L. K., and Sand, H. H., op. cit., pp. 39-40.

In the northernmost part of the Great Plains the bedrocks are overlain by glacial drift, but it is neither extensive nor highly permeable and is not a very productive source of water in most places. In the High Plains, however, extending from eastern New Mexico and the Panhandle of Texas north to Nebraska, the bedrocks are overlain by an extensive sheet of sand, gravel, and clay washed out from the Rocky Mountains since they were raised. These deposits are rather permeable and productive and furnish large yields to wells. They are recharged at a rate ranging from a small fraction of an inch per year in the south to several inches in parts of Nebraska. Where the recharge is low and the pumpage high, as in the southern High Plains of Texas, the withdrawal is largely from storage accumulated in the past and eventually the pumpage must be reduced or the recharge increased by artificial means.

The Great Plains is a region of prevailing deficient water supply, with full development or overdevelopment of ground or surface water in many areas. Current projects of the Bureau of Reclamation and the Corps of Engineers are designed to provide additional water supplies and to reduce flood damage and sedimentation problems in the northern part of the region, including the basins of the Platte and Republican Rivers. The Arkansas and Canadian Rivers are or soon will be fully developed in their headwaters areas, and their lower courses are characterized by high silt loads and very heavy chemical contamination, both natural and man-made. Transmountain diversion from the Colorado River basin will help the southern part of the region to some extent. The Pecos River basin, though strictly not a part of the Great Plains, can be included for the purpose of discussion. The surface water is fully developed; ground water is overdeveloped in some areas in both New Mexico and Texas and there is depletion of stream flow as a result. The water of the Pecos River in the southern part of New Mexico and adjacent area in Texas is very salty, as the result of reuse and of the natural discharge of salty spring water, and is some of the most highly mineralized water in the world used for irrigation. There is some possibility of reducing the salt load in the lower reach of the river by intercepting some of the salty spring water in New Mexico. The river is freshened by springs and tributary inflow before joining the Rio Grande.

Ground water is scanty in the northern part of the Great Plains, though careful exploration reveals supplies adequate for small towns and industries. In the High Plains there is a tremendous amount of stored water, but the recharge is low except in the sand-hills region of Nebraska, and large withdrawals come from storage. The difficulty in deciding what to do about this large but essentially irreplaceable resource has been discussed elsewhere. A point that might be mentioned here is the interstate interference that is not important so far but that will inevitably appear as development increases.

On the whole, only the fullest development of the available supplies, carefully planned to take into account the relations of surface and ground water and the problems of interstate interference and established water rights, will suffice to meet the existing and prospective needs of this region.

Western Mountain Region

The western mountain region includes the remaining part of the country, west of the longitude of the east front of the Rocky Mountains. It is a large region and could well be broken up into a number of regions on the basis of geology, physiography, or climate. It has the greatest range in altitude, from below sea level to more than 14,000 feet above, and in climate, from subtropical to arctic. It includes the driest areas in the country, with practically no precipitation, and the wettest, with more than 100 inches. However, the region is characterized as a whole by mountains and high plateaus receiving relatively abundant precipitation and acting as sources of water that flows into lowlands which receive relatively little precipitation and contribute little runoff. Exceptions to the general rule are the coastal lowlands of the Pacific Northwest, which receive abundant precipitation, and, on the other hand, the lower mountains of the southernmost part of the region, which receive very little, even though more than the adjacent basins.

The maximum runoff ranges from 10 to rarely more than 20 inches in the Rocky Mountains, 20 to 40 inches in the higher part of the Sierra Nevada, and 40 to 80 inches in the Cascades of Oregon and Washington. In the Great Basin between the Sierra Nevada and the Rockies it is rarely more than a few inches even in the mountain ranges and is mostly an inch or less in the lowlands -

less than a quarter of an inch in the driest areas. Many streams carry heavy silt loads and, in some stretches, highly mineralized water.

The region is characterized by mountains built of dense rocks of low permeability, though in most places having a fairly permeable surface mantle of weathered rock; high dissected plateaus formed of stratified rocks of which only the lava rocks of the Northwest are highly productive aquifers; and river valleys and intermountain basins partly filled with alluvium washed from the adjacent mountains. The river valleys and alluvial basins are the most important ground-water reservoirs of the region. From the developed ones is pumped more ground water than in the rest of the country combined, with California in first place and Arizona in second. The lava plains are important contributors to stream flow, but so far the ground water has not been developed heavily by means of wells, except in a few areas.

The water problems of the western mountain region currently are the Nation's most serious and complex, and those calling for the most prompt and comprehensive study, most careful planning, and most complete interstate and international coordination. Because of the general deficiency of and great value of water the region is characterized by the Nation's most detailed hydrologic studies, most ambitious water developments, and greatest development of systems of establishing water rights. But the approach so far has been piecemeal, and there is a lack of fundamental hydrologic data and of an adequate understanding of hydrology on the part of both water users and the courts, and conflict both between ground-water and surface-water rights and between rights based on different concepts of law in adjacent States. The present situation is one of serious overuse of ground or surface water or both in some areas, while water remains for development or is wasted in others; a part of the water not now used for beneficial pruposes cannot be developed under existing laws because to do so would interfere with established rights.

The water needs of the West can be met to a large degree, though the cost will be great and many complex problems will have to be worked out. Large developments in the major river basins will have to be made with an understanding of their relation to each other and to the basin as a whole.

The closed basins of Nevada and Utah, on the whole, are incompletely developed, and they offer considerable promise for increased use of water through salvage of evapo-transpiration waste and storage of flood waters that still escape unused to the playas, there to be evaporated. These basins form one of the brightest spots in the Western water picture, for many of them can be developed successfully on the basis of scientific investigation--largely undone so far--without interbasin and interstate complications. The serious water problems of the West have arisen in parts of the major basins.

Other Areas

Water problems in which we are involved are not confined to the 48 States. Some brief mention should be made of problems in the territories and island possessions and in foreign areas where we have interests.

Of the territories and island possessions the one for which most information is available is the Territory of Hawaii. There surface- and ground-water studies have been under way for many years, but much additional information is needed. The islands are of volcanic origin and are complex geologically and hydrologically, the water situation ranging from island to island and even within an island from one of abundance to one of extreme scarcity. There is heavy development of water, where available, for irrigation and municipal and military uses. On Lanai and Kahoolawe, the driest islands, relatively little water is available and there is a constant need for more. On Hawaii, the largest island, there are large supplies and considerable use, but much water remains for development. On Oahu, the most heavily developed island, numerous water problems exist, principally those of public water supply for Honolulu and water for naval installations and irrigation. The general geology and ground-water conditions are described in a series of bulletins prepared by the Geological Survey in cooperation with and published by the Territorial Division of Hydrography. Much detailed work remains to be done, however, to assure adequate water for the principal uses, especially on Oahu.

Alaska is largely unknown territory so far as water is concerned. Very large potential sources are known to exist, but the growing importance of the territory as a part of the United States and as a key point in our defense means that we will have to accelerate our program of collecting water-resources information to meet the increasing water demands. Water is abundant in many areas but scarce in many areas of use. In the Yukon and Tanana Valleys there are enormous supplies of water, but the surface water carries fine "glacial flour" that settles out slowly and is hard to remove; most of the ground water is high in iron and organic matter. Many communities, especially those along the coast, are in areas of poor water conditions and have difficulty in obtaining good water at feasible cost. The occurrence of permanently frozen ground (permafrost) and the freezing of wells and pipe lines are a serious complication that is not encountered in most parts of the United States.

Surface-water and ground-water investigations in Alaska are only in their infancy. Only a few streams are gaged, and only the briefest of ground-water reconnaissances have been made, in a small part of the area. The increased water developments necessary in stepped-up industrial and defense activities will be very costly if hydrologic studies are not made promptly to permit economical design.

Puerto Rico is a small island of rather large water resources and use. A reconnaissance study of ground water made in cooperation with the Puerto Rico Aqueduct and Sewer Authority showed that probably more than 250 million gallons per day of ground water is pumped, mainly for irrigation of sugar cane on the south coast. Large quantities of surface water are used for irrigation, public supply, and power production. The general poverty of the island and the rapidly increasing demand for water create problems difficult to solve, but strenuous efforts are being made to provide adequate safe water for domestic use. The heavy, increasing, and uncontrolled development of ground water along the south coast is bound to cause overdevelopment and salt water encroachment eventually; they have already occurred in local areas. A large part of the island's economy depends on the sugar cane raised in this coastal strip of less than 200 square miles. Large ground-water supplies are available along the coast in certain other parts of the island and small supplies in the interior. Surface runoff in the interior is moderate but steep slopes make it rapid and necessitate storage reservoirs. The island has a rather large additional water-resources potential, but projects the island can afford are difficult to achieve. Some stream gaging is done by the Water Resources Authority but much more is needed, together with detailed ground-water studies, particularly along the south coast.

The American Virgin Islands are small islands of little water use but very small available supplies. Reconnaissances by the Geological Survey for the General Services Administration, which is developing public supplies, show that water is scarce and expensive to develop and always will be. Detailed ground-water studies are needed to make possible the most economical and largest possible developments, particularly on St. Croix, where there is considerable irrigable land but apparently only a small over-all water supply. There is no surface runoff from the islands except during occasional storms, and storage of surface water is difficult because of steep gradients of streams and a high evaporation rate.

Guam has a perpetual problem of scarcity of water for public and military uses. The Geological Survey has done considerable work on the island and has outlined the principal needs for additional data. Many of the islands occupied by the United States in the Pacific have water problems, including the other Marianas Islands. The Geological Survey has made brief studies of many of the Pacific islands, principally during the last war. The most recent study by the Geological Survey was on Angaur Island in the western Carolines, where a salt-water-encroachment problem is involved. Many additional studies in the Pacific are needed.

FEDERAL CONCERN IN WATER RESOURCES

The interest of the Federal Government in water resources can be summarized briefly as follows:

1. Gathering and interpretation of basic data.
2. Specific water-control and water-development projects, including those for flood and pollution control, reclamation and irrigation, navigation, recreation, fish and wildlife protection, and others; water development for Federal institutions and public lands; and farmstead water supplies on private lands.
3. Legal interests.
4. Development of a sound national water policy.

Basic-Data Program

The Federal Government has a broad responsibility for gathering basic data on the occurrence, quantity, quality, and availability of water resources and for making the data available to the public promptly in such form as to be most useful in assisting and promoting sound, economical water developments, both by the Government itself and by other public and private agencies. The responsibility and justification for this activity are similar in principle to those for providing a sound national currency, uniform laws regulating interstate commerce, and an adequate national defense. In this phase of its participation in the water-resources picture, the interest of the Federal Government is, first, in providing general information useful in the development of water by anyone, no matter what the purpose; and, second, in providing basic information essential for Federal projects involving water.

The basic data are in two principal classes: (1) Data on precipitation and potential evaporation and on the general occurrence and movement of water in the atmosphere; and (2) data on the occurrence of water on and under the ground surface.

The first phase is chiefly the responsibility of the Weather Bureau. Other agencies, however, make intensive studies of precipitation, evaporation, and other meteorological factors as part of intensive hydrologic studies or in connection with specific water-development projects, and the resulting data are published in part by the Weather Bureau.

The second phase is chiefly the responsibility of the Geological Survey. A number of other Federal agencies make similar or related studies as a part of development projects or as a part of research on such subjects as stream pollution and utilization of water by crops and other vegetation. These studies are made in part with the collaboration of the Geological Survey and in part independently. The principal other Federal agencies are the Bureau of Reclamation, the Corps of Engineers, the Forest Service and Soil Conservation Service of the Agriculture Department, and the Public Health Service.

Most states participate in the basic-data program on surface and ground water. Their participation is largely in financial cooperation with the Geological Survey, on a 50-50 basis, where the information produced is of the generally useful type that justifies Federal participation. All the States cooperate in stream gaging and most cooperate in ground-water studies. Certain States--Maine, New Hampshire, Vermont, Illinois, Missouri, South Dakota, and Montana--do not cooperate in State-wide ground-water studies at present. Considerable work by the Geological Survey is being done in South Dakota and Montana under the Missouri Basin program, and a very small amount of work is being done in the others under the program of Federal observation wells. The studies by the States range in scale from rather large, as in Illinois, to very small, as in the upper New England States where ground water is not developed heavily so far. In many of the other

States the cooperative programs are on a small scale.

Many county and municipal governments and water or flood-control districts make water studies, mostly directed toward specific objectives. Where Federal participation is warranted in the public interest, many of these studies are made by the Geological Survey as cooperative projects.

Finally, water studies are made by private companies and consultants. To a large extent these studies utilize basic data gathered by the Weather Bureau, the Geological Survey, and the State agencies as part of their over-all programs, and additional basic data are gathered only where those available are inadequate. The studies by private agencies are directed toward developing water supplies to meet specific needs, and they go beyond the Federal basic-data studies in that they involve computation of costs, selection of specific sources, and design of water systems.

Accomplishments and Deficiencies

The Weather Bureau obtains precipitation data at about 9,000 stations and evaporation data at about 220 stations equipped with standardized instruments. Owing to participation by thousands of unpaid observers, the data are more comprehensive than would otherwise be possible, but they are far from adequate. Many more precipitation and especially evaporation stations are needed. Funds are needed for basic research on existing and needed data on the movements of water in the air, in order to permit more reliable prediction of occurrence and amount of precipitation in all parts of the country, on development and movement of storms, and on evaporation requirements. One of the most important needs is research to permit calculating evaporation on the basis of the known physical properties of water and air, rather than by means of empirical formulas based only on observed data.

The Geological Survey has been gaging streams since 1888 and now measures stream flow at about 6,000 stations in the United States. The data are published in 15 annual volumes covering major drainage basins and groups of basins. Some of the records are now more than 40 years long and so are of considerable and increasing reliability for predicting flow, but most of the records are still too short. Some fairly large streams are still ungaged, and many more stations are needed on small tributary streams in headwater areas, particularly those contributing large quantities of water. As important as the need for more data on flow is the need for research in surface-water hydrology, a field that has had to be neglected because of the demand for more and ever more data on flow. Such research, which would involve largely the correlation of stream flow with ground water, precipitation, evaporation, water uses, and the geologic characteristics of the drainage basins, would permit more reliable predictions of stream flow from short records, permit the extension of records from stations of long records to those with short records, and even permit reasonable prediction of flow from small ungaged basins. In short, the needed research would increase the value of existing records, and those to be collected in the future, many times beyond its cost.

The status of ground-water hydrology is paradoxical. As a science it is considerably advanced; yet, so far as national coverage is concerned, it is only in an early stage. The studies so far, and to a large extent those of surface water, too, have been largely on a "disaster-relief" basis--they have been made in response to compelling needs for information in regard to specific water needs and water shortages. Thus, detailed studies have been made in areas of existing or proposed heavy withdrawal, and the need for making reliable estimates, yet with a minimum expenditure of time and money, of quantities of water available has stimulated research to the extent that methods have been developed for making quantitative estimates under widely different hydrologic conditions. At the same time, the basic studies to determine ground-water conditions throughout the Nation have lagged. The reason is that provision has never been made for a coordinated national study of either ground water or surface water, to say nothing of water as a whole. The bulk of the money available has been State funds and the matching Federal funds and the studies have had to be directed toward specific needs. Unobligated Federal funds, though increasing, are still inadequate for the balanced approach to the over-all occurrence and availability of water that is the indispensable prerequisite for a sound national water policy.

Nearly 2,000 reports and papers on ground water have been published by the Geological Survey and cooperating agencies. Those published through January 1946 are listed in Water-Supply Paper 992,_/ and several hundred have been published since. Also, several hundred unpublished reports are in the files of the Geological Survey. The reports represent a large amount of scientific investigation, but the coverage is far from complete. Perhaps a quarter of the country is covered by basic reports, some a good deal more complete than others, describing the general geology and occurrence and quality of ground water. For the rest of the country only reconnaissance studies have been made, or none at all; in the latter areas the only way of predicting the occurrence of ground water is from the geology, so far as known from geologic studies made for other purposes, and the climate. Probably less than 5 percent

_/ Waring, G. A., and Meinzer, O. E., Bibliography and index of publications relating to ground water prepared by the Geological Survey and cooperating agencies: U. S. Geol. Survey Water-Supply Paper 992, 1947.

of the country is covered by detailed studies that permit reasonably reliable statements as to actual quantities of water available and the basic conditions governing their development for useful purposes. Figure 18 shows in a general way the areas for which substantial information is available--areas for which existing data represent a large fraction of those needed for proper planning of future developments so far as they can be predicted.

In addition to--or rather as a fundamental part of--the studies needed to provide adequate information on our ground-water resources is research on the following important subjects, among others: _/

_/ Meinzer, O. E., U. S. Geol. Survey, Report on ground water by the Research Committee of the Society of Economic Geologists: Econ. Geology, vol. 42, no. 7, pp. 672-675, November 1947.

1. Hydraulics of ground water. The fundamentals of ground-water flow under ideal conditions are fairly well known, but there is a possibility that additional research would make fundamental changes in existing concepts. Also, because aquifers in nature do not meet the ideal conditions assumed in the basic equations, much additional laboratory and field research is needed to permit determining ground-water flow in nonuniform aquifers, such as those bounded by impermeable rocks or sources of recharge like rivers, those which change rapidly in thickness and permeability, those artesian aquifers having leaky confining beds, and those aquifers bounded by faults which may either impede or facilitate the flow of water.

2. Physics of soil moisture in relation to ground-water recharge, discharge, and storage. Intensive studies have been made by soil physicists of infiltration into the soil, but these studies are not complete and the related subject of unsaturated flow above the water table is little known.

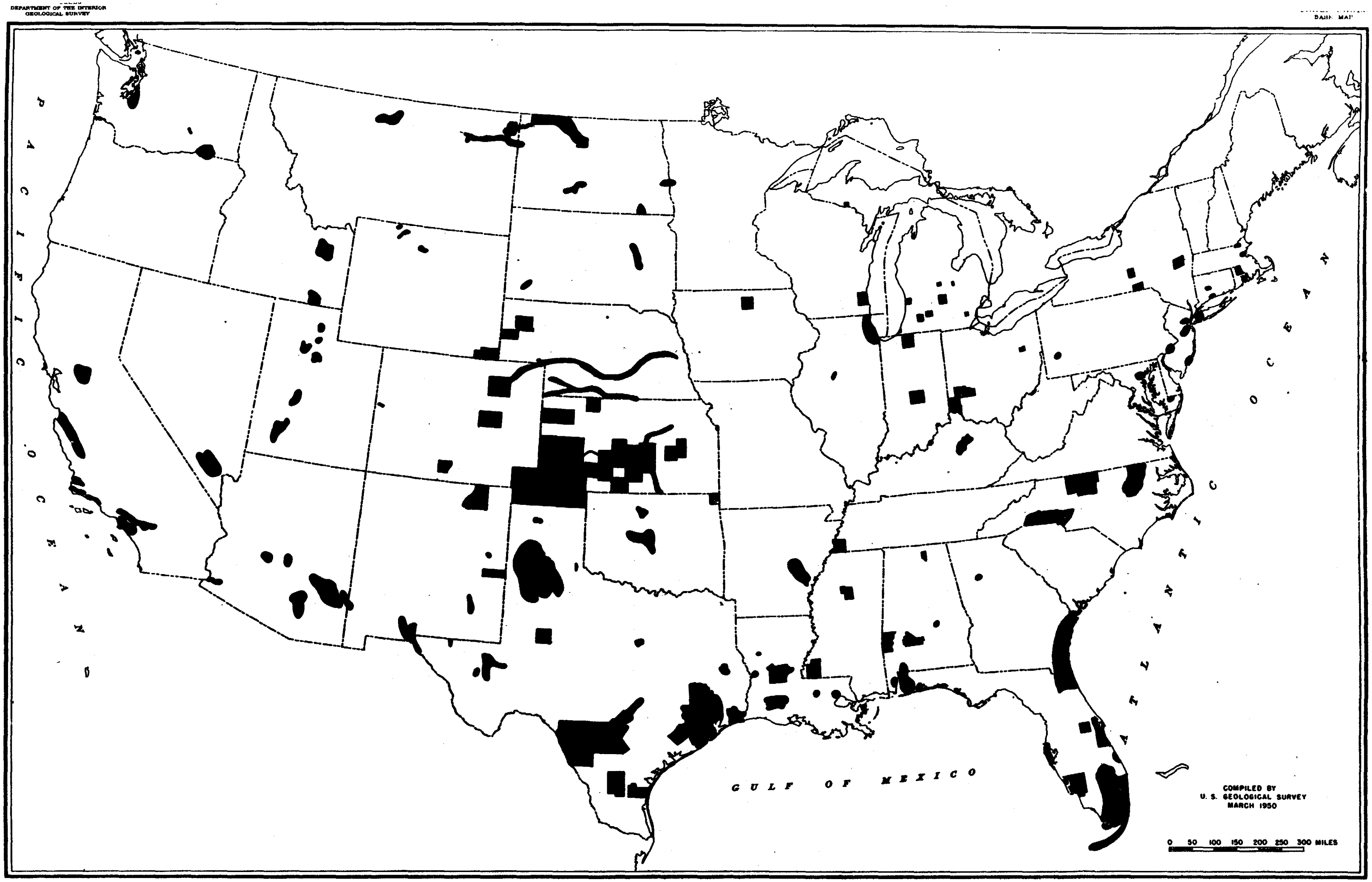

FIGURE 18. AREAS OF SUBSTANTIAL GROUND-WATER INFORMATION

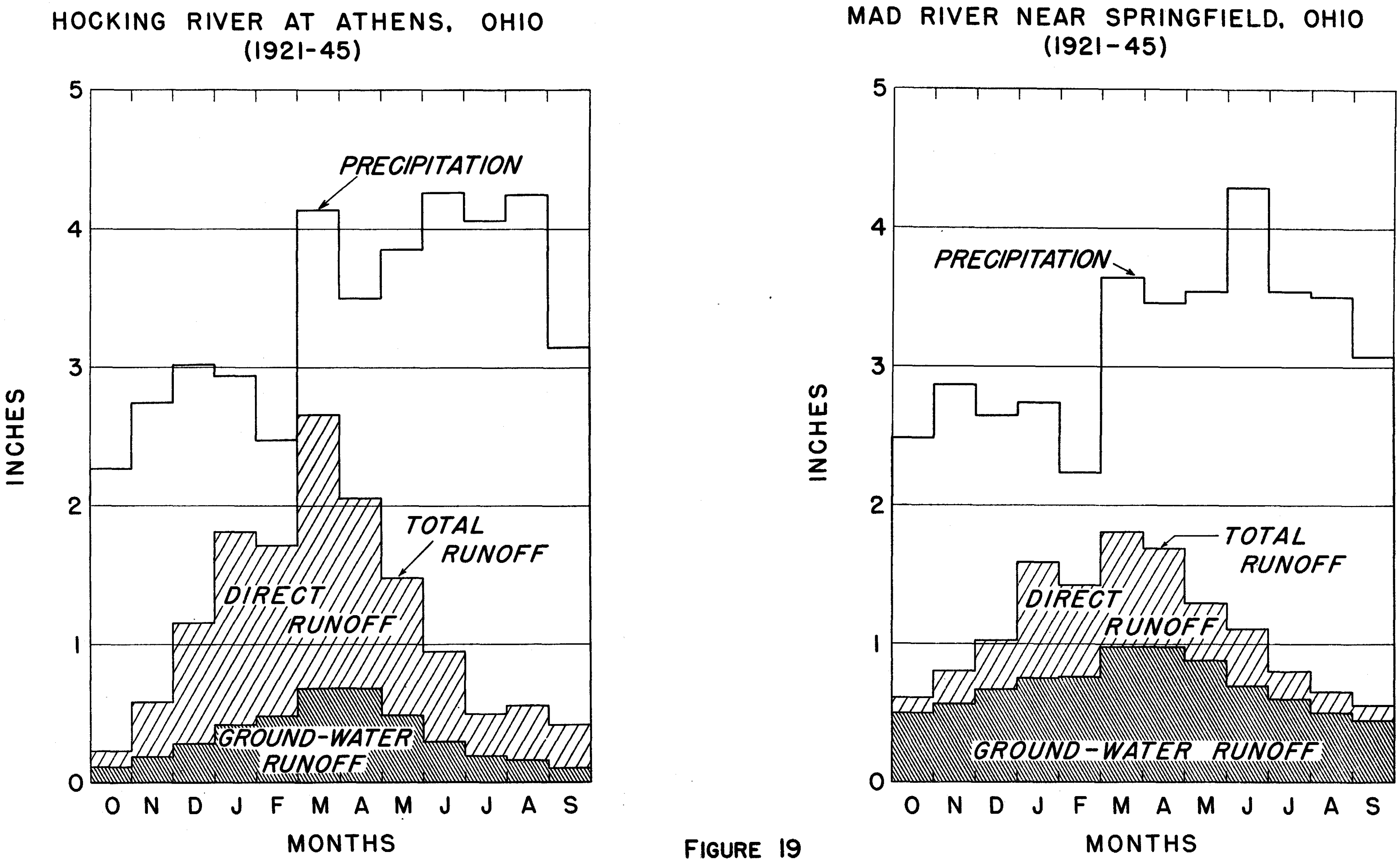

FIGURE 19

AVERAGE MONTHLY PRECIPITATION AND RUNOFF FOR TWO OHIO STREAMS SHOWING EQUALIZING EFFECT OF STORAGE IN THE GROUND-WATER RESERVOIR

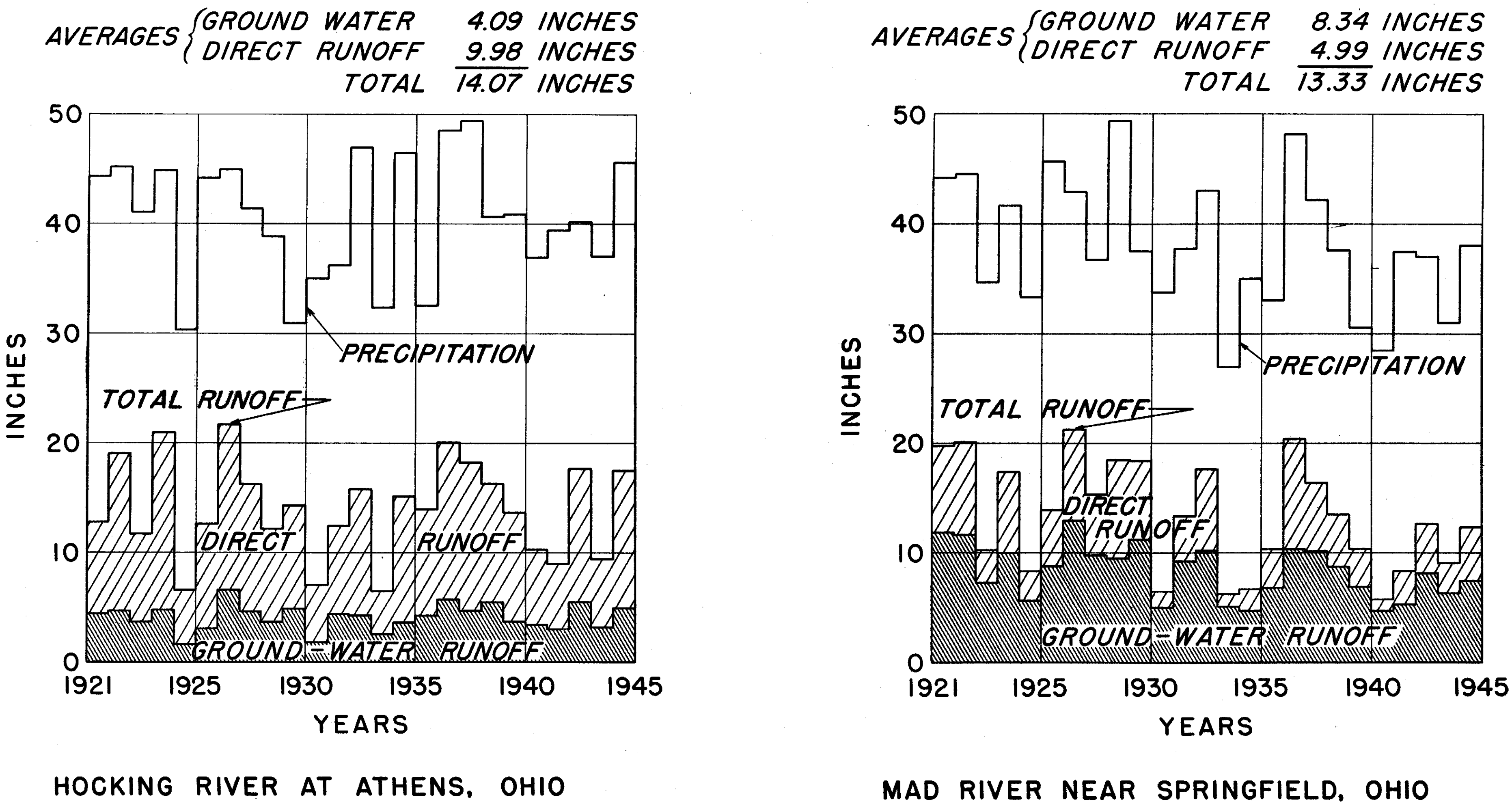

FIGURE 20

ANNUAL PRECIPITATION AND RUNOFF FOR TWO OHIO STREAMS SHOWING EFFECT OF STORAGE IN THE GROUND-WATER RESERVOIR

3. Artificial recharge. Research is needed to develop practical methods for artificial recharge, in relation to different geologic conditions, quality of water, and variable rate of supply.

4. Correlation of records of water-level fluctuations in wells. The water levels in wells show the stage of the underground reservoirs. Their fluctuations reflect all the natural and artificial factors that affect the passage of water into, through, and out of the reservoirs, in addition to such forces as changes in atmospheric pressure; tides in the earth's crust; changes in load on the earth's crust as a result of tides in coastal areas, changes in water level in lakes, streams, and reservoirs, and even the passage of railroad trains; and earthquakes. Methods must be developed for separating and identifying fluctuations caused by the different agencies, in order to permit interpreting the fluctuations in terms of quantities of water available.

5. Geophysical exploration. Geophysical techniques, some already used widely in searching for oil, are finding increased usefulness in locating and identifying aquifers as a low-cost supplement to test drilling; in determining the precise depth to water-bearing and non-water-bearing beds in drill holes and the approximate quality of the water; in exploring wells to locate leaks and determine movement of water between separate aquifers in which the water is under different heads; and in many other ways. Much additional research on instruments and methods is needed.

6. Texture and structure of rocks in relation to ground water. The occurrence in and movement of water through rock formations in relation to the texture of the rocks and the attitude of water-bearing and non-water-bearing

rocks is incompletely understood. A good example is limestone, perhaps the most variable water-bearing rock.

7. Geochemistry of ground water. Research is needed to determine the sources of chemical constituents in ground water and the way in which they are dissolved. This field has great promise in identifying sources of water and routes of movement, and in studying the occurrence of minerals in the deposition of which ground water may have had a part—for example, uranium-bearing minerals of the Colorado Plateau and the iron minerals of the Great Lakes region. Such research may lead to more successful and economical prospecting for and estimation of reserves of such minerals.

8. Salt-water balance. Considerable work has been done in coastal areas, but much remains to be learned concerning the physical principles governing the occurrence and movement of salty ground water. The importance of such research to the many coastal areas depending on ground water is obvious.

9. Bacterial and industrial pollution of ground water and the purifying capacity of rocks. This broad field, of great and increasing importance, is still poorly understood. Coordinated research by hydrologists, bacteriologists, and sanitary engineers is much needed.

10. Interrelationship of ground water and stream flow. Studies in this vast field, one of the most important in hydrology and one with which we will be concerned more and more as the use of water increases, are in a very early stage.

The Geological Survey has been making studies of water quality and sediment loads of streams for nearly half a century. In coordination with stream-flow studies, the suitability of water supplies for municipal, industrial, or agricultural uses is determined by systematic sampling programs at nearly 200 points in major drainage basins throughout the United States. Observations of temperature of surface waters are also being made at hundreds of locations over the country. Measurement of fluvial sediment transported by streams is undertaken at more than 100 regular stations in several major drainage basins, notably in the western part of the United States. The data are published in annual volumes, bringing under one cover all such information available for the United States during any particular year. Notwithstanding the scope of past and present studies, there are vast areas in the United States where little or no information is available concerning the chemical quality and suspended loads of the surface-water supplies. Present comprehensive studies are being made of surface waters in only a few areas, largely in cooperation with State agencies as local needs arise. Though water quality has been considered in previous ground-water investigations, there are wide areas of the country for which little or no information is available concerning the chemical composition of ground-water supplies. In addition to deficiencies in the scope of such basic programs, research in certain fundamental problems in sediment transportation and factors governing the chemical composition of natural waters would be fruitful. Such research would be pointed to the fundamental factors governing the quantities of material in solution and in suspension in natural waters, including the variations in suspended and dissolved material as related to precipitation, topographic and geologic features, vegetation, and human activities.

Time has not been available for a review of the accomplishments of other agencies making basic-data studies on water, such as the Soil Conservation Service, the Forest Service and other agencies of the Agriculture Department, the Army Engineers, the Bureau of Reclamation, the Public Health Service, State agencies, universities, and private companies and consultants. All of them have made substantial contributions to hydrology, and all of them have much work yet to do. A general review of deficiencies in hydrologic information is found in two reports of the National Resources Planning Board.[1] Many

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[1] Deficiencies in basic hydrologic data: Nat. Resources Committee, September 1936; Deficiencies in hydrologic research: Special Advisory Committee on Hydrologic Data, Nat. Resources Planning Board, 1940.

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of the agencies will be preparing reports for the Water Resources Policy Commission that will review their past work and the needs for future studies.

Though a more comprehensive picture of the needs for basic data and research on water would be desirable, the preceding is sufficient to show that we are still a have-not Nation in basic information on water. The most critical needs for basic data might be summarized as follows:

1. A comprehensive inventory of all water uses--in terms of gross volume at source and of net volumes dissipated and rendered unfit for reuse, by areas which are both economic and hydrologic units. Once established, this inventory should be maintained on a current basis. Only the crudest of over-all estimates are now available.

2. A comprehensive appraisal of the Nation's water-yielding capacity, by natural hydrologic units. Here, "capacity" has the sense of all water available in each unit area, whether in the streams or in the ground. We have only incomplete, basic records, largely not analyzed.

3. A continual determination of water quality--in terms of chemical constituents, temperature, and sediment--for both natural waters and domestic,

industrial, and irrigation effluents. We have only fragmentary information, by no means up to date.

4. A balance-sheet accounting of all available waters against current and prospective uses--with appropriate encumbrances for the dilution of wastes, conservation of fish and wild life, navigation, and other obligations. Such an accounting should be instituted just as soon as a nucleus of basic facts can be assembled, as it is essential to economic security.

5. In general, a store of water data adequate to assure economical design and ultimate full-scale operation of water projects now contemplated or apt to be needed in the not-too-distant future. For no State or major drainage basin do currently available water facts satisfy this standard. Against the needs of a decade hence, adequate strengthening of basic networks of water-measuring stations should be undertaken promptly.

Specific Water Projects

The largest "action programs" in the water field in which the Federal Government participates are the comprehensive flood-control and navigation projects of the Army Engineers throughout the country and the reclamation projects of the Bureau of Reclamation in the 17 Western States. Closely related are the soil- and moisture-conservation and farmstead water-supply projects of the Soil Conservation Service on private lands and of the Interior Department on public lands, and the forest-management work of the Forest Service.

Increasing Federal participation in water projects is inevitable, especially where interstate and international drainage basins are concerned, or where the economy of an important segment of the population is affected even though the basin is entirely within a State--for example, the Central Valley of California. In order that the projects may be carried out in accordance with the Constitution and the rights of the States and of private enterprise, there must be close cooperation and coordination of effort among Federal, State, county, municipal, and private agencies. Nothing could be more damaging to the effort to make our water supplies secure than a feeling on the part of Federal agencies that only Federal interests need be considered or on the part of State and local interests that the Federal Government has no place in the solution of water problems that affect the public welfare.

The Federal Government has a direct interest in providing water supplies for Federal institutions and public lands. Among these supplies are those for military installations both here and abroad, veterans' hospitals, Coast Guard installations, Federal prisons, national parks and monuments, stock and domestic uses on public and Indian lands, public systems developed with the assistance of the General Services Administration, Federal housing projects, and others. These water supplies are developed by the responsible agencies or by contract with private construction firms. The Geological Survey is generally asked to furnish the data upon which to base the design; in its work on water problems of Federal installations and public lands the Geological Survey often furnishes consulting service also. A substantial part of the Survey's water-resources investigations are financed by direct appropriation for Federal needs or by repayment by the agency concerned.

The water problems of the public lands, in the solution of which the Survey acts both as source of basic data and consultant, are discussed below in a little more detail, as one phase of Federal water activity in which the Survey plays more than its usual part.

The water problems of the public lands center largely on (1) their utilization for grazing, (2) safeguarding the water supplies of the streams that originate on the public lands or flow through them, and (3) maintaining the productivity of the public lands.

The efficient utilization of the public lands for grazing requires, as an ideal, sources of stock water at a maximum spacing of 6 miles. Such a distribution has been attained in few areas so far. Vast areas of forage are ungrazed or lightly grazed because of remoteness from water; others close to water are overgrazed to the point of destruction of the range. Geologic and hydrologic studies are needed to develop additional water supplies.

Wells, where they can be developed, are the ideal source because of their dependability. Impounding surface water in reservoirs provides dependable water in many places, but the water is dependent on rainfall, and the reservoirs are subject to evaporation, seepage, and sedimentation. As a result, many stock-water reservoirs are failures. However, such reservoirs are the only feasible means of developing water in many parts of the range. Studies are needed to determine places where surface-water supplies can be developed, and the basis of proper design to assure dependable water. The question as to the aggregate effects of the large numbers of stock-water reservoirs upon downstream water users has been raised in many quarters. Very little is known about the matter, despite the importance of the problem in the Western mountain region.

Soil erosion on the public lands, particularly gullying, is a serious problem. The gullies, most of them now 60 to 70 years old and some of them as deep as 40 to 50 feet and tens of miles in length, are subdraining many valleys of their ground water and lowering the streams so that they are no longer useful for irrigating pasture or farm lands. The causes of this large-scale erosion are as yet obscure, and coordinated studies by soil scientists, hydrologists, geologists, and ecologists are needed to work out the basic causes, so that practical methods can be evolved for arresting or retarding the further development of the existing gullies and to prevent new ones from forming.

Legal Interests

The Federal Government has the responsibility of making agreements providing for the division of the waters of international drainage basins, and for seeing that the conditions of the agreements are met by this country. Among the international agreements made thus far are those made under the jurisdiction of the International Joint Commission, set up in accordance with the treaty of 1909 between the United States and Canada. Water questions involving the United States and Mexico are under the jurisdiction of the International Boundary and Water Commission.

The Federal Government also has a substantial interest in the formulation of interstate compacts covering agreements on water questions. Among the typical interstate compacts are those for the Colorado, Delaware, Republican, Arkansas, and Pecos Rivers and the Rio Grande. Many more are in existence, and a still larger number will have to be made in the future as water development increases and the knotty problems of interstate division of water are worked out. Interstate ground-water problems have not yet come to the fore in most parts of the country, but they are bound to be increasingly important, and future agreements will have to take all water, surface and ground, into account.

The Federal Government also has the problem of protecting, by legal means, the water supply of Federal installations, and of determining the extent to which the Government is bound by State water law. Such problems have not been serious so far but more are bound to develop as water use increases.

A large part of this report has dealt with the necessity of coordinated development of the water resources of the Nation and with the great possibilities offered by manipulation of the underground reservoirs and the associated surface streams to provide adequate water supplies when and where needed and to prevent or minimize floods and pollution. Such manipulation means legal control. Intelligent development cannot be made except within a framework of law that will permit achieving the desired objective and preventing activities that would defeat the purpose of the development. The subject of water law, which will be covered in a separate report, represents one of the most complicated phases of the water-resources picture and one of the most difficult to treat, yet legal problems must be worked out if our water developments are to be successful and our water supplies secure.

The Geological Survey, as a basic-data agency, has no part in the enforcement of water law. It has, however, an important part to play in helping to evaluate, from a hydrologic standpoint, the soundness and enforceability of existing or proposed legislation. Much of the existing water law is unsound hydrologically and can be enforced not at all or only at the expense of efficient development and maximum utilization of water. It is essential, therefore, that a body of workable water law be built up and put to use. The degree of regulation should be the minimum necessary for effective control. Voluntary cooperation by water users is essential and should be depended on so far as possible; without such cooperation, achieved through an adequate educational effort, any law, even the most stringent, is likely to be partially or wholly unsuccessful.

It is the opinion of the Geological Survey that, constitutional objections aside, a uniform Federal law for control of water would be impractical because of the wide variation in occurrence and utilization of water and in existing State laws. It is believed that legal problems involved in the control of water can be enacted most effectively at the State level, and interstate problems can be handled by compacts. What should be uniform throughout the country is the soundness of the State laws from a hydrologic standpoint: If they are sound hydrologically then those of adjacent States will be compatible, or, if not based on the same principle of law, at least will not interfere with formulation of interstate compacts where they are necessary.

Our National Water Policy

Should there or can there be such a thing as a National water policy? The tremendous variety of water conditions in the Nation, the extreme ease with which large supplies of good water can be obtained in some areas and the difficulty and expense of getting even small supplies of poor water in others, the shortages of water in some areas and the undisturbed natural conditions in others, all point to the difficulty of establishing a uniform over-all policy. Yet on all sides we can see a trend toward increasing use of water and increasing cost of getting it, and so we can come to the conclusion that if a National water policy will help to make our water supplies secure for the future we should establish one. With respect to such a policy, the Geological Survey suggests consideration of five principles within the scope of its direct concern, as follows:

1. The Federal Government will gather, analyze, and disseminate comprehensive and balanced water facts adequate to overcome the deficiencies outlined previously; also, commensurate with its responsibility for the economic and physical security of the Nation, and with its "action" programs for development and management of water and soil resources.

2. Recognizing a mutuality of interest in water problems, the Federal Government will collaborate with States and their agencies in acquiring and disseminating supplemental water facts essential to State functions. Currently the Federal Government bears not to exceed half the total cost of such investigations.

3. To assure the integrity and impartiality of such service and to assure public confidence, the determination of these basic water facts shall, to the maximum extent practicable, be a responsibility of an agency or agencies administratively distinct from those charged with Federal "action" programs.

4. The current water situation shall be reported to the public as promptly as feasible, in understandable terms. The American public, heretofore inadequately informed about water and somewhat complacent as to its availability, is becoming aroused to the gravity of water problems and will welcome assistance

toward prudent, long-range water management. It can so act only with an understanding of the impact that each new development may have on the optimum water capacity of each basin involved.

5. The Federal Government will encourage enactment of State laws and interstate compacts that foster water management for optimum yield, especially with respect to ground water. Present water law involves some principles incompatible with ground-water hydrology, and with fundamentals of basin-wide optimum-yield management. In various localities the growing demand soon may force water users to achieve equitable allocations through mutual and hydrologically sound action within a framework of hydrologically sound statutes.

SELECTED READING LIST

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APPENDIX

SUMMARY OF CURRENT WATER SITUATION

BY STATES

The accompanying table was prepared to accompany the report to the President's Water Resources Policy Commission entitled, "Water facts in relation to a national water-resources policy." Although the table does not give a complete picture for any State, it presents some of the general water conditions, problems, deficiencies in basic data, and steps that have been taken or could be taken to solve the problems or provide additional water supplies.

The table was prepared mainly from the data that could be assembled in the field offices of the Geological Survey in the brief time available. Because the investigative programs vary widely from State to State in scope, completeness, and objectives, and because time was not available for thorough coordination of the data, the presentation is spotty, in places the data are inadequate, and the emphasis is most uneven. The table does, however, give some idea of the tremendous number and variety of water problems in the Nation, and its very inadequacy serves to emphasize the lack of uniformity and coordination that exists in both water investigations and water projects.

The table presents information on all phases of water problems and possible solutions as the Geological Survey understands them on the basis of the available data. It is not intended to imply that the Geological Survey is concerned directly with problems outside the basic-data field and the solution of water problems on the public lands--that is, that the Survey is concerned with problems involving the economic evaluation or selection of water sources, design of systems, or enforcement of water law. Thus, when specific mention is made of the apparent availability or unavailability of an economical source of water to meet an existing deficiency, or of the need for data on feasible methods of pollution control, or of the need for regulation of ground-water use to avoid over-development, it is intended only to point out the existence of a problem as known to the Geological Survey, whether or not the Survey is directly concerned with its solution. The position of the Geological Survey is set forth in the following statement adapted from "United States Geological Survey: Water-resources responsibility and participation," prepared for the President's Water Resources Policy Commission as a part of "Agency Reports--Legal," item I:

The responsibility of the United States Geological Survey in the field of water resources relates essentially to its recognized position as the primary agency of the Federal Government for the collection of the relevant basic data. Although the information it collects contributes importantly to the development, utilization, and conservation of the water resources, it is not directly responsible for such activities, except in connection with some aspects of the administration of public lands. It performs research and functions in advisory phases of land-use practices for the land-management agencies of the Interior Department concerned with the above-mentioned responsibilities. Its participation in all these activities is, however, indispensable to the assurance of soundly based programs of water-resources development, utilization, and conservation.

The Geological Survey's primary function in regard to our water resources is to perform surveys, investigations, and research covering the water resources of the United States and its territories and possessions, and to publish and disseminate data relative to these activities. It engages in the investigation and evaluation of the Nation's water resources for all uses, both governmental and nongovernmental, insofar as they relate to the public interest. It is a research and service agency whose findings provide the basis for innumerable projects, large and small. Its activities provide a guide to the formulation of water-development plans. Furthermore, its findings are impartial; and it has no authority to enforce the acceptance of its conclusions.

APPENDIX

SUMMARY OF CURRENT WATER SITUATION BY STATES

Alabama

About 50 m.g.d. of ground water and 100 m.g.d. of surface water used for public supply. Moderate to large supplies of ground water available in Coastal Plain and in parts of area of Paleozoic rocks in northern part of State. Smaller supplies available in Piedmont, where larger municipal and industrial uses are from streams. Few water problems except in limited areas. Ample water available if properly investigated and developed. Some small towns may have difficulty in financing adequate developments. Additional gaging stations needed, and studies of problems relating to flood flows. Studies of ground water needed to determine safe yield in developed areas. Studies needed also in Piedmont Plateau of east-central Alabama.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Mobile	Encroachment of salt water into shallow aquifers, by infiltration from brackish Mobile River. Public supply as now developed inadequate for present and future needs.	Information on ground-water potential for industrial use.	Mobile is building new surface public-supply reservoir to provide adequate water for domestic and industrial use. Additional ground water may be available from deeper aquifers within and north of city for industrial and suburban use.
Tuscaloosa-Birmingham-Gadsden area	No serious problem at present, Birmingham will need expanded supply, possibly within 5 years. Base flow of streams in Birmingham-Tuscaloosa part of area inadequate; storage needed. Base flow in Gadsden part of area adequate. Ground water in Birmingham-Tuscaloosa part inadequate for large development. Black Warrior River polluted from Birmingham past Tuscaloosa.	Ground-water potential for small-scale industrial and other use.	Ample supplies probably can be obtained by building storage reservoirs on small streams.
Montgomery	Increased demand and lowering of water levels in closely spaced wells in old well field have necessitated a new well field.	Intensive studies to determine amount of ground water available from wells located over an increasingly larger area.	Additional water appears to be available from wells, but they should be located on the basis of detailed studies that have not been made. Water available from Alabama River if ever needed, either directly or by river infiltration.
Selma	Possible inadequacy of present wells.	Hydraulic characteristics of aquifers and proper spacing of wells.	Additional water available from properly located wells. Water available from Alabama River if ever needed.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Huntsville area	Large supply developed from Huntsville Spring.	Detailed study needed to determine dependable yield.	
Tuscumbia-Sheffield area, Dothan area, Andalusia area	Large ground-water developments made.	Detailed studies needed to guard against overdevelopment.	

Arizona

Second largest ground-water user in Nation. Ground water overdeveloped in principal basins of southern Arizona because of increasing withdrawal for irrigation of new lands and to supplement surface-water supplies made inadequate by drought in recent years. Intensive studies of safe yields of principal basins and of potential yields of a number of undeveloped basins needed. No major source of water to reduce overdraft apparent, except Colorado River. Total use about 5 million acre-feet in 1949, 1.8 surface water and 3.2 ground water. Waste by nonbeneficial vegetation estimated crudely at 1.4 million acre-feet per year, of which about half possibly could be salvaged.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
San Simon Basin, Cochise County	Withdrawal of ground water 5,800 acre-feet in 1946, larger now. About 1/4 of water from flowing wells wasted or used inefficiently. New development starting in Rodeo area, in New Mexico part of basin. Potential interstate water problem.	Accurate determination of perennial yield of basin. Information as to effect on present development of new development in Rodeo area. Amount of artesian water discharged underground at shallow depth because of inadequately cased wells.	Stopping underground leakage from defective wells and increasing efficiency of use may bring withdrawal within safe limit, if not increased otherwise.
Willcox Basin, Cochise County	Waste of water by water-loving plants (phreatophytes). Withdrawal from wells about 28,000 acre-feet in 1949, about 75,000 acre-feet wasted by evapo-transpiration in and near Willcox Playa.	Determination of amount of water salvageable from present waste. Safe yield of basin under present conditions and with salvage of some of natural waste.	Salvage of natural waste would make present withdrawal safe and perhaps permit increasing it substantially.
Douglas Basin, Cochise County	At present rate of development, safe yield of basin may eventually be exceeded; withdrawal 30,000 acre-feet in 1949. Basin is part of larger basin extending into Mexico; possible international interference and legal complications.	Safe yield of basin as a whole.	Development of maximum safe yield by international agreement.
Upper San Pedro Basin, Cochise County	Many of old flowing artesian wells are leaky and much water is lost underground. This loss and that by phreatophytes along San Pedro River channel may exceed amount of water used by crops.	Amounts of water used and lost and safe yield of basin not known at present.	Salvage of losses.
Coconino County	Surface-water supplies not reliable in time of drought. Large supplies of ground water probably not available except with extreme pumping lifts.	Availability of ground water.	Ground water may be available for use of towns, but probably not for irrigation.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Globe-Miami area, Gila County	Developed supplies of water of good quality inadequate; water of poor quality used from mines. Acid drainage from waste piles at mines reported to have contaminated several wells supplying domestic water at Miami. Towns and mines are searching for new supplies.	Availability of ground or surface water within reasonable distance.	Towns and mines could cooperate to bring in sufficient quantities of water from nearest dependable source.
Safford Basin, Graham County	32,000 acres irrigated, partly from Gila River and partly from wells, depending on availability of river water. Of 210,000 acre-feet used in 1949, 40,000 or 19 percent was from wells. In 1946, 62 percent of the total of 185,000 came from wells. About 30,000 acre-feet per year is wasted by phreatophytes in lower 2/3 of basin.	Practicability of eliminating phreatophytes. Ownership of the water that would be saved if the phreatophytes were eliminated.	Salvage of waste by phreatophytes.
Cactus Flat-Artesia area, Graham County	Withdrawal from artesian wells about 16,000 acre-feet in 1949. Water lost through leaky well casings and by non-beneficial phreatophytes.	Amounts of water lost and practicability of reducing waste by phreatophytes.	Repair of leaky well casings; salvage of water now wasted by phreatophytes.
Duncan Basin, Greenlee County	Possible interstate problem, as basin is part of larger Duncan-Virden Basin extending into New Mexico. Withdrawal about 15,000 acre-feet in 1949 for 4,700 acres in Arizona and 3,000 in New Mexico; has ranged from 1,350 to 27,000 acre-feet since 1939.	Safe yield of basin as a whole, which is not known. Close relationship of ground-water developments to flow of Gila River.	Maximum safe development by interstate agreement.
Salt springs in Greenlee County	Salt springs discharge into San Francisco River, and into Gila River near west border of county.	Detailed study of springs, including possible methods of intercepting salt-water flow and disposing of it.	Interception of salt water would improve conditions in entire part of Gila Basin below the springs.
Salt River Valley area, Maricopa	Ground water overdrawn, surface water inadequate. Draft from wells 1,680,000 acre-feet in area in 1949. Declines in water level most rapid in Deer Valley and Queen Creek areas and others where little or no surface water is available. Salt content of ground water increasing at west end of Salt River Valley area.	Determination of safe yield of ground water under different conditions of stream flow; minimum outflow necessary to keep salt content down; use of water by phreatophytes and possible salvage.	Bureau of Reclamation proposes to divert 1,200,000 acre-feet per year from Colorado River for Central Arizona project. Salvage of water wasted by phreatophytes. Interception of salt water upstream on Salt River would improve conditions in Salt River Valley area.

Arizona—Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Gila Bend area, Maricopa County	Salt content of ground water increasing, owing to decreased outflow. Withdrawal about 70,000 acre-feet in 1949; water levels declining only in areas of heaviest pumping.	Methods of decreasing salinity of ground water, by increasing outflow through salvage of waste and reduction of withdrawal. Use of water by phreatophytes and possible salvage.	Proposed Central Arizona project by Bureau of Reclamation would increase inflow to this area.
Waterman Wash area, Maricopa County	New development starting. Available supply may be small.	Determination of safe yield.	Holding withdrawal to safe yield.
Colorado River Valley, Mohave County	Irrigation from shallow wells along Colorado River flood plain; question of water rights.	Effect of ground-water withdrawals on flow of Colorado and on prior rights to its water.	
Santa Cruz Basin, Pinal, Pima, and Santa Cruz Counties	Ground-water withdrawal in 1949, 1,100,000 acre-feet in lower part, 150,000 in middle, and 31,000 in upper. Safe yield exceeded, especially in lower part where recharge is estimated at 135,000 acre-feet per year; situation less serious so far in upper part. Supply supplemented by surface water only in northeasternmost part of basin.	Better determination of safe yield and of practicable withdrawals in each part of basin. Possibility of salvaging waste by phreatophytes, especially at north end of basin along Gila River.	Reduction of withdrawal to safe yield. ("Eloy critical area" established by State in 1948; no new development permitted.) Importation of water if available. Agreement with Mexico, into which upper part of basin extends, may eventually be necessary.
Avra area, Pima County	Water levels declining at northern end of area because of local pumping and pumping to the north.	Information on safe yield.	Holding or reducing withdrawal to safe yield.
Wellton-Mohawk area, Yuma County	Ground water overdeveloped (withdrawal 49,900 acre-feet in 1948); salt content of water increasing because of decreased inflow.	Determination of minimum outflow necessary to keep salt content down.	Holding ground-water withdrawal to safe yield. Bureau of Reclamation building canals for importation from Colorado River.
Yuma area, including "South Gila Valley," Yuma County	Water table rising in flood plain because of irrigation with Colorado River water on both flood plain and higher "Yuma Mesa"; waterlogging and salt accumulation occurring.	Practicability of stopping rise of water table and accumulation of salt.	Pumping to lower water table and prevent waterlogging (already done in places); use of water in such a way as to prevent salt accumulation.
Dateland area, Yuma County, and Hyder area, Maricopa County	Small areas between Wellton-Mohawk and Gila Bend areas. Withdrawal 5,300 acre-feet in Dateland area in 1948; development just beginning in Hyder area. Existing or potential problems similar to those in Wellton-Mohawk area.	Determination of safe yield. Determination of minimum outflow necessary to keep salt content down.	Holding ground-water withdrawal to safe yield.

Area or Subject	Current situation	Deficiencies in information	Corrective measures and further development
St. Johns and Hunt areas, Apache County	Principal ground-water development is from Coconino sandstone. Water is under artesian pressure. Some surface water is available in St. Johns area. Successful irrigation wells have been developed. Safe yield of area has not been exceeded.	Amount of additional ground water available.	Some additional ground-water development can be made without exceeding safe yield.
Lower San Pedro Basin, Pinal, Cochise, Pima, and Graham Counties	Present development is principally from nonartesian aquifers; a few successful artesian wells have been developed. Nonbeneficial use of water by phreatophytes along river bottom.	Determination of safe yield of basin. Amount of water used by phreatophytes. Practicability of eliminating phreatophytes.	Salvage of waste by eliminating phreatophytes. Hold development to annual safe yield.
Arivaipa area, Graham County	Small amount of ground water pumped for irrigation. Some surface water in northern end of area. Amount of arable land probably will limit ground-water development.	Safe yield of area. More information about ground-water movement in area.	Hold development to safe yield.
Centennial Wash area, Maricopa County	Development of ground water is increasing slowly. Increase in depth to water in a northwesterly direction probably will limit development.	Safe yield of area.	Hold development to safe yield.
Valentine and Wickieup areas, Mohave County	Ground water used to irrigate a few small tracts in Valentine area and to supplement surface-water supply in Wickieup area. Total pumpage is small.	Safe yield of areas. Availability of additional supplies.	Hold development to safe yield.
Holbrook and Show Low-Taylor areas, Navajo County	Coconino sandstone is principal aquifer from which water is being developed at present. Recharge area of sandstone is along southern rim of Colorado Plateau. The water in the sandstone near Holbrook is under sufficient pressure to produce flowing wells. Ground-water development is on small scale.	Amount of additional ground water available.	Some additional ground-water development can be made without exceeding safe yield.
Chino Valley, Yavapai County	Artesian system is being depleted by loss to permeable beds at shallow depth because of inadequate casing in some wells.	Determination of amount of water discharged from artesian system at the surface and as loss to permeable beds at shallow depth. Safe yield of basin as a whole.	Stopping underground leakage from inadequately cased wells. Controlling all nonbeneficial surface flow. Hold development to safe yield of basin.

Arizona--Continued

Area or subject	Current situation	Deficiencies in information	Corrective measure and further development
Bouse area, Yuma County	Area of new ground-water development for irrigation. Difficult and expensive to locate and develop a satisfactory irrigation well.	Annual safe yield of the area.	Hold development to annual safe yield.

Arkansas

Relatively few water-supply problems, that in Grand Prairie region most serious. Large reserve supplies available in many other areas. Water-resources data scanty; information needed on quantity and quality of water available from smaller streams and on extent and yield of ground-water reservoirs. Ground water especially important in Coastal Plain, surface water in northwest half of State. Flood control needed, especially in Coastal Plain.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Arkansas River Valley in "Paleozoic upland" (northwest half of State)	Quality of river water unsuitable for irrigation of certain types of soils, and river carries sediment. Large ground-water supplies available from river alluvium, and development on a large scale probable.	Information on availability of water from alluvium, and on present quality of water and possible changes with pumping.	Developing ground water in such a way as to prevent undesirable changes in quality of the water by "induced recharge" from river.
"Paleozoic upland"	Only small to moderate ground-water supplies available.	More data on availability of ground water where surface-water development is impracticable. Information on water from the smaller streams.	Large supplies of surface water of good quality available from base flow or by constructing storage reservoirs.
Streams in Coastal Plain (southeast half of State)	Impounding streams generally not practicable because of low gradients; thus only large streams like Arkansas, St. Francis, Ouachita, White, Red, and Mississippi Rivers are dependable for large sustained yields. Arkansas River water of poor quality and river carries sediment. Red River carries heavy sediment load. Lower Ouachita River polluted and needs treatment for many uses. Flood problems in valleys of larger streams.	General studies of pollution and flood control.	Very large additional developments of surface water possible. Pollution should be reduced and erosion checked in headwater areas to reduce sediment content, where these conditions exist and correction is feasible. Flood-control measures needed. Large supplies of ground water available in many areas where surface-water development is too costly.
Grand Prairie region	Shallow aquifer overdeveloped by pumping for rice irrigation; water from deeper aquifers insufficient to make up deficiency or too costly to develop.	Effect of application of surface water on shallow ground-water. Practicability of recharge of surplus surface water into shallow aquifer.	Development of surface-water supply to supplement ground water. Project now proposed by Army Engineers, to get water from White River.
El Dorado area	Some lowering of ground-water levels due to local development of more than 10 million gallons per day.		Decline not believed to indicate regional overdevelopment; more ground water available outside area of heavy pumping. Ouachita River, 11 miles northeast, potential source if needed; treatment of water required.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Crossett area	Local decline of ground-water levels due to heavy pumping.		Regional overdevelopment not indicated. More ground water available outside heavily pumped area. Ouachita River nearby if needed; treatment required.
Pine Bluff Arsenal	Contamination of certain wells by arsenical waste.		Contamination readily controllable by proper disposal practices and well-construction methods.
Ground water in Coastal Plain in general	Recharge of shallow aquifer (eastern quarter of State) and of some deeper aquifers limited by overlying impermeable beds. Supplies generally abundant except in local areas.	Occurrence and potential yield of aquifers; quality of water in different aquifers and at different depths.	Large supplies available from both shallow and deep aquifers in areas not now heavily pumped. Withdrawals should be made in accordance with results of basic studies still to be made.

California

Leads Nation in total use of ground water and in use of surface water for irrigation. Annual runoff has averaged 70 million acre-feet but in driest 10-year period of record averaged only half as much. In areas of heavy water use a large part of runoff does not reach the sea. Present water use (excluding hydro-power) about 20 million, ultimate requirement according to State about 39 million acre-feet per year (including 10 million for Great Basin area). Total water supply, including that under Colorado River rights, adequate to meet needs but extensive systems required for transporting water, mainly from relatively wet north to water-short south. Flood-control works necessary in all parts of State; many can be combined with conservation works. Full use of storage capacity of ground-water basins needed in California Water Plan. Salt-water or other chemical contamination occurring in several important areas, principally Sacramento-San Joaquin Delta, Salinas and Santa Clara Valleys, and South Coastal Basin in Los Angeles and Orange Counties; levels declining in part of Sacramento and much of San Joaquin Valleys and in 29 of 36 other principal ground-water basins; actual overdraft known to be occurring in small part of Sacramento and much of San Joaquin, and in parts or all of 13 others.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
North Coast area Includes 10.1 percent of area of State and 337,000 (2 percent) of total of 16,670,000 acres of irrigable land, but has 41.4 percent of runoff; largest undeveloped source of water. Average annual runoff 29 million acre-feet, present use ½ million or less, and ultimate only 1 million.	No important problems except flood control on lower Smith, Eel, and Russian Rivers.	Better data on runoff as source of surplus water for other areas.	
Modoc lava plateau		Ground-water potential.	Large yields of wells in Butte area suggest possible ground-water developments in Modoc plateau to utilize water now escaping to ocean or atmosphere.
Santa Rosa Valley	Only one of the half dozen ground-water basins in North Coast area now developed appreciably; estimated 10,000-15,000 acre-feet pumped annually. No over-all depletion but some local shortages. Increased irrigation development expected. Local bacterial contamination of wells, including iron bacteria in Santa Rosa city wells.	Perennial yield of basin; ground-water studies now in progress. Studies to determine necessity for and practicability of importing Russian River water.	

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
San Francisco Bay area Includes 2.8 percent of total and 5.2 percent of irrigable land in State. Average runoff 1.4 percent of total, or 1.24 million acre-feet per year; in driest 10-year period was only half as much and in driest year less than 1/8 as much.	Water requirement now half a million acre-feet per year, ultimate 2.72 million or 6.9 percent of State total. Area depends in part and will continue to depend on imported water.	Analysis of stream-flow records for prediction of average and minimum yields.	Conservation works to increase supply from local sources; increased use of irrigation-return water from ground-water reservoir as importations increase; increased importation from Sierra Nevada, from present sources and from proposed Folsom Reservoir on American River or Oroville Reservoir on Feather River, proposed as part of California Water Plan. Possible importation from north coastal streams.
Petaluma Valley	Ground water not now overpumped but development limited by brackish water beneath tide lands; increase in draft (probably not more than 3,000 acre-feet per year now) may cause salt-water encroachment.	Safe yield of ground water under present conditions and with importation of water. Study now under way.	Importation of Russian River water if safe yield of ground water proves inadequate for present and proposed needs.
Napa and Sonoma Valleys	Present draft on ground water 10,000 to 15,000 acre-feet per year. No general overdraft apparent, but local shortages due to poor aquifers or brackish water. Increased draft may cause salt-water encroachment. Locally boron content of ground waters is too high for irrigation.	Safe yield of ground water (study under way).	Importation of water if necessary.
Ygnacio Valley	Withdrawals probably exceeded safe yield of ground waters in past.		Water now available from Contra Costa Canal of Central Valley Project.
Livermore Valley	Ground-water draft about 17,000 acre-feet in 1948 for irrigation, industrial, and municipal supply, including a well field for San Francisco. Small overdraft.	Studies (now under way by State) to determine whether importation of water will be necessary.	Overdraft on ground water has created usable underground storage capacity of about 100,000 acre-feet; possibly can be utilized by construction of detention reservoirs on Arroyo Mocho and Arroyo del Valle, which would permit flood water now wasted to recharge ground-water reservoir.

California--Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Central Valley area Includes 37.4 percent of total area and 59.8 percent of irrigable land. Average runoff 48.6 percent of total, or 34 million acre-feet per year, but in individual years has varied from a fourth to twice as much. Ultimate requirement 52.7 percent of State total, or about 18.2 million acre-feet plus 2.4 million for salinity repulsion in Sacramento--San Joaquin Delta. Runoff of Sacramento Valley portion over 2/3 of total, irrigable land a little over 40 percent.	Sacramento Valley part of area is one of surplus water and San Joaquin one of shortage. Central Valley Project, initial unit of California Water Plan, designed to distribute water more evenly, prevent waste, provide flood control, and halt encroachment of salt water in Upper Bay and Delta region. Shasta Reservoir will provide flood control and water for power generation, navigation, and salinity control, and for irrigation and other uses in Sacramento Valley and delta area; and water for lower San Joaquin Valley, via Delta Cross Channels and Delta-Mendota Canal, to replace water now used from San Joaquin River. Ground-water storage capacity of San Joaquin Valley will be used to bridge dry years. Friant Reservoir, via Madera and Friant-Kern Canals, will supply water to central and upper San Joaquin Valley, now largely pumped from wells. Artificial recharge of aquifers in upper San Joaquin Valley will be essential to restore depleted supplies and store flood waters. Additional projects proposed by Bureau of Reclamation and Army Engineers will provide for irrigation of 3 million acres not now irrigated, for other uses, and for flood control and power production.	Additional stream-flow data on ungaged streams and on releases and spill from new reservoirs; analysis of records to enable better prediction of water available in different parts of Central Valley. Storage capacity of ground-water reservoirs in Sacramento Valley (preliminary report prepared.) Location of favorable areas and methods for artificial recharge in upper San Joaquin Valley (study in progress). Data on quality of water--natural runoff, irrigation return water, and ground water, to assist in operation of project; data scant except in delta region. Data on sediment in streams where reservoirs or flood-control works are planned. Data on contamination by industrial waste and sewage. The principal need is for careful investigation of the occurrence and movement of ground water and the underground storage volume and recharge potential of the San Joaquin Valley.	Present gross draft on ground water in Sacramento Valley is 1 million acre-feet per year, net draft less than half as much. More unused ground-water storage available than in any other area of State. Ground-water storage capacity between depths of 20 and 200 feet estimated at 28 million acre-feet. Utilization of ground water not only would provide useful storage space but would salvage large amount of water now wasted by phreatophytes, providing additional surplus water for export to south.
Sacramento Valley "Peach Bowl" area of Sutter County west of Feather River and parts of Yuba and Placer Counties east of river.	Local overdraft of ground water.		Importing water from adjacent areas of high water table caused by surface-water irrigation (now under investigation by State).

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Kelseyville area	Ground-water draft of 14,000 acre-feet per year; overdraft estimated at 5,000.		State studying methods of alleviating overdraft.
Fairfield area, Solano County (part of San Francisco Bay area)	Overdraft of ground water; aquifers thin and storage virtually depleted.		Importing water from main part of Sacramento Valley, or construction of Monticello Reservoir.
Southwestern Sutter County	Encroachment of salty water caused by heavy pumping from wells.		Reduction of draft and importation of water.
Areas irrigated from Cache Creek in Yolo County	High boron content in irrigation water.		Importation of better water.
San Joaquin Valley	Draft estimated at 7 million acre-feet from 40,000 wells in year ending March 1948, of which 1 million was from deep wells on west side. Water levels still high and only local overdrafts in Kern River fan and in and north of Kings River fan. Severe overdraft on east side of valley between Kings and Kern River fans and south of Kern River fan, estimated ½ to 1 million acre-feet per year. Severe overdraft also on west side south of Fresno-Merced County line, estimated at ½ million acre-feet per year or more. Shallower waters high in salt, which is being added to land and must be disposed of. Water levels declining and may reach economic limit within the relatively near future. Salt accumulation may ruin large areas of productive land.	Practicability of artificial recharge and best areas for it. Available data not adequate to assume success of the project.	For east side, artificial recharge with flood water for use in dry years, as part of Central Valley project. As much as 16 to 18 million acre-feet must be put underground, at rates of as much as 3 million per year, without waterlogging land, and must be available by pumping from wells. For west side, importation of water to halt overdraft and prevent salt accumulation in soil.

California--Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Santa Clara Valley	Ground water chief source of water. Draft now probably more than 200,000 acre-feet per year. Water levels in Santa Clara County declined average of 108 feet from 1915 to 1934, recovered 70 feet to 1943, and have declined nearly 100 feet since 1943. Present deficiency of water estimated to be 38,000 acre-feet; possibly 100,000 ultimately. Serious salt-water encroachment from bay.	Detailed study of water resources, now being completed in Santa Clara County and started in Alameda County by State.	Reduction of overdraft to halt salt-water encroachment and drive salt water back. Existing and proposed storage reservoirs will reduce deficiency in part; reclamation of part of 250,000 acre-feet per year of sewage effluent discharging into San Francisco Bay being considered. New reservoir on Coyote Creek now under construction.
Central Coast area Includes 7.1 percent of total and 3.7 percent of irrigable land in State. Runoff 2.9 percent of total or 2 million acre-feet.	Ultimate requirement about 1.5 million acre-feet per year; supplies now available slightly deficient on average and seriously deficient in certain areas, particularly some in Santa Barbara County.	Additional stream-flow data in most of area; fairly good data available for Santa Barbara County and Salinas and San Benito (Hollister) Basins. Ground-water data needed for most of area; good data available for Santa Barbara County and Salinas Basin. Data on quality and sediment content of water needed for much of area.	Full development of water resources of area, with importation of water as needed.
Hollister area	Southern extension of Santa Clara Valley, but drains to Monterey Bay. Ground-water draft estimated at 60,000 to 70,000 acre-feet per year; overdraft exists but magnitude not known. Excess boron in ground water in eastern part of area.	Perennial yield of basin (now being studied by Bureau of Reclamation).	Construction of a storage reservoir or use of ground-water storage created by overdraft, to salvage flood waters, if found economically feasible.
Salinas Basin	Ground-water draft of 360,000 acre-feet per year supplies most of irrigation requirement. Total water supply in basin exceeds ultimate requirement but overdraft exists in two major subareas. Salt-water encroachment from Monterey Bay and concentration of salt by evaporation of shallow water also create problems.		State suggests salvage of natural waste and more efficient irrigation practices; possible use of sewage effluent for irrigation; repair of defective wells; and pumping and transportation of water from areas of surplus to those of shortage. Construction of storage reservoirs on tributaries of Salinas River.
Cuyama Valley, Santa Barbara County	Ground-water draft about 20,000 acre-feet in 1948, nearly twice estimated perennial recharge under natural conditions; local concentration of salt in soil.		Importation of water.

Area of subject	Current situation	Deficiencies in information	Corrective measures and further development
Santa Maria Valley, Santa Barbara County	Ground-water draft about 100,000 acre-feet per year, perennial yield under present conditions about 53,000. Salt-water intrusion will occur if present overdraft continues.		Conservation of flood waters to increase total supply and prevent flood damage; may not meet ultimate requirement and importation of water may be necessary.
Santa Ynez River Valley, Santa Barbara County	Includes several basins along Santa Ynez River. Total ground-water draft about 30,000 acre-feet per year; replenishment depends in part on amount of runoff in river. Average annual runoff about 124,000 acre-feet. Sea-water encroachment possible, but only with increased ground-water draft.		Cachuma Reservoir under construction by Bureau of Reclamation will store 210,000 acre-feet, reducing waste of water to sea and flood damage and making available part of proposed ultimate yield of 33,000 acre-feet per year for use in Santa Ynez River Valley.
Goleta Basin and city of Santa Barbara, Santa Barbara County	Present ground-water draft in Goleta Basin about 9,000, perennial yield under natural conditions about 3,100 acre-feet per year. Salt-water contamination threatened. Silting and drought forced temporary disuse of surface reservoir of City of Santa Barbara and draft of about 3,000 acre-feet of ground water in 1948; continued pumping may cause sea-water encroachment.		Cachuma project will supply water from Santa Ynez River to overcome deficiency in Goleta Basin and City of Santa Barbara.
Carpinteria Basin, Santa Barbara County	Ground-water draft 3,000 to 5,000 acre-feet in recent years; estimated perennial yield under natural conditions 1,700 acre-feet per year. Sea-water encroachment appears to be starting. Ground water high in boron in one area.		Cachuma project will supply water to overcome deficiency.
South Coast area Includes basins draining to Pacific from Ventura County southward. Includes 6.8 percent of total and 12 percent of irrigable land in State. Runoff 1.4 percent of total or 1 million acre-feet per year;	Area is one of severe deficiency. Developed practically all local water by 1900 and began importing water, first from Owens Valley and then from Colorado River. Loss of flood water to sea occurs irregularly and salvage is impracticable. Sedimentation of reservoirs a serious problem. Local contamination of surface water by irrigation-return water high in chloride, and by industrial wastes in Los Angeles and San Gabriel Rivers. Some surface waters	Surface-water data fairly adequate except for special studies. Ground-water studies substantial but more adequate data needed on perennial yield and methods of increasing ground-water recharge and halting salt-water encroachment. Data needed on quality and sediment content of water, including practicability of reclaiming sewage. Comprehensive ground-water data available for parts of area; more accurate determinations of safe yield needed.	Importation of water to meet deficiency.

California--Continued

Area of subject	Current situation	Deficiencies in information	Corrective measures and further development
ultimate requirement 3.3 million acre-feet per year or 8.4 percent of State total.	high in boron. Ground-water basins, and water of area as a whole, about as fully developed as in any area of the United States. Current annual pumpage is about 1 million acre-feet.		
Oxnard-Santa Clara Basin	Ground-water draft about 200,000 acre-feet per year. Draft in Oxnard Plain, where water is largely artesian, about 60,000 acre-feet and overdraft in dry periods about 30,000 acre-feet per year. Water levels now below sea level in much of plain; salt water encroaching in vicinity of Ventura and threatening entire coastal section. Santa Clara part of basin inland recharged freely by Santa Clara River and not overdrawn. Contamination by industrial wastes possible locally.	Availability of water within basin to meet deficiency (now under study by Santa Clara Water Conservation District).	About 100,000 acre-feet annually needed to meet deficiency and future needs and prevent salt-water encroachment. If found to be not available within basin through conservation, surface storage, and utilization of ground-water storage, importation from outside basin will be needed.
San Fernando and San Gabriel Valleys	Total ground-water draft about 200,000 acre-feet per year. Basins not appreciably overdrawn but water levels declining in San Gabriel Valley. Contamination by recharge from polluted waters of Los Angeles and San Gabriel Rivers is principal problem.	Studies of methods of pollution control (under way by State and Los Angeles County).	Alluvium of San Fernando Valley being used for artificial recharge of some flood water and some water from Owens Valley; water levels have risen since 1934.
Coastal Plain in Los Angeles and Orange Counties	Ground water principal source except for Owens River and Colorado River water used for public supply and two water districts; surface water diverted for irrigation at Whittier Narrows and in Santa Ana Canyon. Ground-water draft about 400,000 acre-feet per year, 80 percent in main basin and 20 percent in West Basin. Draft in main basin about 25,000 acre-feet more than recharge as of 1947; about twice recharge in West Basin. Water levels below sea level in most of coastal plain, and salt water encroaching along coast of West Basin in Los Angeles County and of main	Feasibility of artificial recharge and reduction of pumpage to raise water levels at coast; reclamation of sewage water (under study by State and local areas).	Water of West Basin under adjudication by State; water being imported from Colorado River Aqueduct. Attempts being made to reduce draft in main basin to rate of replenishment; adjudication may be necessary. Pollution-control measures under way.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further developments
	basin in Orange County; has moved as much as 2 miles inland. Contamination also by oil-field and industrial wastes, from surface and from Los Angeles River.		
Upper Santa Ana Valley	Ground-water overdraft of about 20,000 acre-feet per year. Water of Santa Ana River system fully utilized. Contamination by industrial wastes and other water of poor quality possible locally.	Pollution-control studies (under way by State and local agencies).	Importation of water. Certain local agencies are planning to join Metropolitan Water District and use Colorado River water; this and perhaps other outside sources will be used to meet deficiency.
San Diego County coastal basins	Total ground-water draft about 30,000 acre-feet per year. Salt-water encroachment in Santa Margarita, San Diego, and Tia Juana Valleys.		Pumpage curtailed by State in Tia Juana Valley, water supply under adjudication. Colorado River water being imported (70,000 acre-feet in 1948). Additional importation will be necessary if about 400,000 acres of land suitable for irrigation or home sites are to be utilized.
Great Basin area Includes area east of Sierra Nevada except Goose Lake Basin and area directly tributary to Colorado River; 34.8 percent of total and 17.3 percent of irrigable land in State. Runoff 4.3 percent of total or about 3 million acre-feet per year.	Ultimate water requirement according to State is about 10 million acre-feet. Area thus is seriously deficient in water if such a requirement is to be met.	Stream-flow data for area north of Lake Tahoe, in vicinity of Salton Sea, and tributaries of Owens River. Ground water largely unstudied.	For area as a whole, importation of water would be necessary to meet ultimate requirement. Large ground-water storage available in certain valleys but perennial recharge probably small because of aridity. Moderate developments probably feasible, however, if adequate studies are made.
Owens Valley	In 1929-31 Los Angeles pumped a total of 340,000 acre-feet of water from wells, and water levels declined.		Basin fully recharged now and comparatively little use is made of ground water, which constitutes a reserve supply for Los Angeles.

California--Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Indian Wells Valley (Inyokern area)	About 100,000 acres suitable for agriculture. Perennial yield of ground water estimated in 1912 to be sufficient only for perhaps 1,500-2,500 acres; only 800 under cultivation by 1919. Current draft about 2,000 acre-feet per year.	More accurate determination of perennial yield.	
Antelope Valley	Total available water supply estimated at 63,000 acre-feet per year; net draft about 109,000 acre-feet in 1947. Importation of about 400,000 acre-feet annually needed to meet ultimate requirements. About 7,000 acre-feet recharged from Owens Valley aqueduct in year 1946-47.		Importation of water and utilization of ground-water storage, as feasible, to meet deficiency and provide for additional development.
Mojave River basins	Includes large and more or less connected alluvial basins along Mojave River. Recharge largely from river.	Perennial yield.	Development of maximum supply, including salvage of natural waste by phreatophytes, estimated by State at 40,000 acre-feet per year.
Coachella and Imperial Valleys	Two basins lie in a structural depression and are separated by Salton Sea. Ground-water withdrawal in Coachella Valley about 125,000 acre-feet per year and may be within perennial yield. Some water imported from Colorado River. If more is imported, waterlogging may develop near Salton Sea, as in Imperial Valley where ground water is not abundant and irrigation with Colorado River water has raised water table in the slightly permeable valley fill.	Safe yield of Coachella Valley and methods to avoid waterlogging if irrigation is increased. Drainage conditions in Imperial Valley (comprehensive studies made by Soil Conservation Service).	

Colorado

More surface water originates in Colorado than in adjacent States but must be shared with States in which downstream parts of basins lie. Surface supply east of Continental Divide long overdeveloped; much more irrigable land than water for it. Diversion from west side only source of large new surface supplies; such diversion, and development of area west of divide, will be accelerated now that Upper Basin water of Colorado River has been allocated. Data needed on availability of surface water for specific purposes; on relation of surface to ground water; and on occurrence of ground water throughout State. Principal ground-water supplies are east of divide.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
South Platte River Valley and adjacent valleys	Large withdrawal of ground water for irrigation, supplied mainly by infiltration of surface water; about 154,800 acre-feet in 1948 between Hardin and Sterling, Colo., and 43,500 acre-feet between Sterling, Colo., and Paxton, Nebr. No data for area west of Hardin and for most of tributary valleys, but pumpage believed large. Ground water and surface water closely related and form a common supply. Some overdevelopment in tributary valleys such as Bijou and Big Beaver Creek Valleys, Box Elder Valley near Wellington, and Prospect Valley (latter area now recovering). Some present and potential waterlogging. Potential problem of interstate interference from ground-water pumping.	Studies above Hardin and in tributary valleys, and continuing studies in main part of valley needed to determine all factors related to safe yield of basin, especially relation of ground and surface water and possible salvage of waste by coordinated development.	Coordinated development of basin to prevent local overdevelopment, waterlogging, and waste of water; interstate agreement on ground water as well as surface water to permit full development.
High Plains of northeastern Colorado	Surficial sands and gravels (Ogallala and Arikaree formations) form an important ground-water reservoir; this and minor aquifers furnish all water used in area. No known areas of overdevelopment yet, but some areas have only scanty supplies; also, there is a possibility that large-scale development would have same result as in geologically similar High Plains of Texas.	Practically no studies made so far. Data needed on all phases of occurrence and quality of water.	Development of supply to full potential, but held within safe limits; can be done only on basis of studies not yet made.
Denver basin, including "Denver artesian basin"	Small to moderate supplies of ground water of good to fair quality available. Irrigation supplies not available. "Denver artesian basin" overdeveloped.	Availability and quality of water throughout basin. Studies made so far only in Big Sandy Creek area and to a limited extent in "Denver artesian basin". Safe yield of latter not known.	Determining safe yield of "Denver artesian basin" and holding withdrawal to it; developing remainder of basin safely in accordance with results of studies yet to be made.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Arkansas River Basin	Conditions and problems similar to those of South Platte River Valley. Quality of river water deteriorates downstream. Overdevelopment of tributary valleys possible, but data inadequate.	Comprehensive water-resources study of whole basin. Ground water studied so far only in upper Big Sandy Creek area and in Huerfano County.	Coordinated development of water, considering interrelationship of ground and surface water and interstate aspect. Additional irrigation development feasible in parts of basin if adequately controlled.
High Plains of southeastern Colorado	Conditions similar to those in northeastern Colorado except that aquifer is less productive. Irrigation supplies available only in favorable parts of area. No serious problems so far.	Study of Baca County, covering most of area, completed. Studies needed for rest of area.	Development based on sound hydrologic information, to prevent overdevelopment as in High Plains of Texas.
Bear Creek Artesian area, Baca County	No serious problem so far. Overdevelopment likely if too many irrigation wells are drilled. Interstate aspects.	Safe yield of artesian water.	Holding withdrawal to safe yield. Integration of use on either side of State line.
Arkansas Valley artesian area	Artesian water available in Arkansas Valley from Pueblo County to Kansas line. Water of better quality than that in alluvium, has been overdeveloped locally as at Rocky Ford, and has had to be replaced by hard water from alluvium or river.	Potential yield of artesian aquifers.	Artesian water represents valuable supply in area otherwise having only hard water. Development should be held within safe limits in each locality.
Canon City artesian area	Small but productive area; larger yields than average from Dakota sandstone, and large yield of highly mineralized water from a deeper limestone.	Information on safe yield.	Controlled development to hold withdrawal to safe yield.
San Luis Valley	A major basin having both artesian and unconfined water. Irrigation with Rio Grande water and pumping from wells. Waterlogging and accummulation of salt in low area has migrated westward, ruining more and more farm land. Pumping from shallow beds has lowered water table and interfered with practice of "subirrigation" (irrigation depending on shallow water table rather than application of water at surface) in other areas. No problems of overpumping yet; local overdevelopment possible south of Ft. Garland if too many wells are drilled.	Safe yield of basin as a whole and of individual parts. Feasibility of increasing irrigation withdrawals from wells. Possibility of locating drains in waterlogged area and discharging water into Rio Grande in exchange for increased diversions upstream. Poor quality of this water is a problem, because of standards set in Rio Grande Compact.	Coordinated development of basin to permit maximum beneficial use and elimination of waste by phreatophytes, and yet adhere to terms of Rio Grande Compact with regard to quantity and quality of water passing the New Mexico line.

Colorado—Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Alluvium in valleys of Colorado River and tributaries in western Colorado	No problem at present.	Extent to which water can be developed from alluvium within this part of Colorado, where ground-water supplies are scanty.	Development appears to be practicable only in limited areas. Relation of ground-water use to surface water must be considered.
Grand Junction artesian basin	Artesian supplies available in an area of otherwise scanty supplies; local overdevelopment has occurred.	Detailed study, nearing completion.	Wider spacing of wells to prevent local excessive drawdown; shutting off all flowing wells when not in use; repairing or plugging leaky casings.
Artesia artesian basin	Water of good quality from flowing artesian wells supplies several small towns.	Geologic occurrence of water, limits and extent of aquifers, quality of water, potential yield.	Further development may be possible.
Montrose artesian basin	Artesian supplies available locally in an area of otherwise scanty supplies.	Data lacking as to quantity and quality of water, extent of area, and depth to aquifer.	Additional development for needed stock and domestic water dependent upon studies yet to be made.

Connecticut

Some local water problems but good promise for additional development, as sources are located and evaluated by scientific investigation. Stream pollution serious in some areas but being abated. No serious declines of ground-water levels, but local contamination by salt water or by wastes in streams. Large additional ground-water supplies appear to be available in Still River, Canaan, Quinnipiac River-Farmington, northern Connecticut Valley, Willimantic-Shetucket River, and Quinebaug River areas; need evaluation. Ample surface supplies appear to be available for prospective uses also, but not readily reached in all cases. Irrigation with ground water in tobacco-vegetable-growing area in northern Connecticut Valley especially promising. Basic data on availability and quality of water from small streams and ground-water reservoirs rather meager; needed for water-supply, highway and dam design, and pollution-abatement purposes.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Stream pollution	Of 5,000+ miles of stream channels, about 200 miles are excessively and 400 more miles detrimentally polluted. About 195 million gallons per day of domestic sewage, 62 percent treated, and 120 m.g.d. of industrial wastes, 20 percent treated, are discharged into streams. Principal badly polluted streams are Byram, Noroton, Still, Naugatuck, Quinnipiac, Pequabuck, Park, Mattabesset, Scantic, Hockanum, Willimantic, Yantic, Little, Quinebaug, French, Moosup, Pachaug, and Pawcatuck Rivers and Roaring and Oxoboxo Brooks.	Economical methods for eliminating pollution or treating polluted water.	Excellent progress made through State and private action. It is expected that within 5 years 96 percent of sewage and 75 percent of industrial waste will be treated.
Flood control	Problems exist at scattered localities.		Projects already in operation on Connecticut River and tributaries in Hartford area. Projects under way on Shetucket, Natchaug, and Mad Rivers. Projects under consideration by Army Engineers and State include Andover Dam on Hop River, Coventry Dam on Willimantic River, Thomaston Dam on Naugatuck River, and comprehensive project for Housatonic River.
Bridgeport area	Local overpumping has induced salt water to encroach into ground-water bodies, and care is necessary to avoid contamination by infiltration of polluted surface water also.	Data on ground-water withdrawal and determination of safe yield with various distributions of wells.	Reduction of pumping in localities of heaviest withdrawal, wider spacing of wells, and reduction of pollution in surface water. Substantial progress being made.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
New Haven area	Local overpumping has lowered ground-water levels and induced encroachment of salty and polluted water from Long Island Sound and Quinnipiac and Mill Rivers. Withdrawal of about 4.4 m.g.d. does not exceed safe yield of area as a whole. Water used mainly for processing and cooling, where bacteriological quality is not so important.	Determination of safe yield. Data largely lacking.	Similar to Bridgeport area.
Waterbury-Naugatuck area	Care is necessary to avoid contamination of ground water by industrial and human wastes in Naugatuck River. Safe yield of area as a whole not exceeded by withdrawal of about 11 m.g.d.	Determination of safe yield and of relation of distance from river to extent of pollution. Evaluation of nearby sources of ground water.	Locating wells as far as possible from river; reduction of pollution in river. Additional ground water available in tributary valleys.

Delaware

Relatively few serious problems, but basic data on surface water inadequate and almost lacking for ground water. Considerable promise for additional developments if based on adequate data. Supplemental irrigation with ground water promising in southern part of State. Present use only a small fraction of potential.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Wilmington area	Ground-water withdrawals in southern part of area approaching or exceeding recharge. Brandywine Creek (source of city supply) polluted.	Detailed study to determine safe yield.	Holding ground-water withdrawal to safe yield. Additional water available from Brandywine Creek by construction of storage reservoir. Pollution being corrected by Brandywine Valley Association and others.
New Castle area	Local overdevelopment of ground water in shallow terrace deposits used by city; problem of contamination also.	Study to determine availability of water in terrace deposits outside area of heavy pumping, and in deeper aquifers.	
Lewes area	Salt-water encroachment into aquifers through overpumping and construction of a canal admitting salt water.	Safe yield under present conditions; availability of additional supplies within economical distance.	Well field installed on opposite side of town from contaminated field.
Stream pollution	Delaware River and Brandywine Creek polluted; also lower stretches of most other principal streams.	Extent of pollution and methods of abatement.	See Wilmington area.
Drainage problems	Large areas, especially southwestern Kent and northwestern Sussex Counties, have too much water and need draining.	Study to determine areas needing drainage and most economical methods.	It is proposed eventually to drain 300,000 acres in Sussex County and 150,000 in Kent County.
Iron in ground water	Most ground water in State has excessive iron content.	Study of methods of removing iron economically for domestic use.	

District of Columbia

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Public supply	Public supply diverted from Potomac River in Maryland. Low flow about 500 m. g. d.; withdrawal about 168 m. g. d. in 1949. Water in river polluted.		Water-supply source adequate but additional treatment and distribution facilities needed. Pollution control, possibly in part by upstream storage to obtain larger low flow and greater dilution, is a possibility.
Ground water	Ground-water withdrawal not large because of lack of industry.	Ground-water data badly needed; no adequate study ever made.	Small supplies available for domestic use in northwest part, small to large supplies in Coastal Plain, increasing to southeast. Adequate data would assist development for "heat-pump" heating and cooling installations and other uses.

Florida

General situation favorable. Large supplies available for development in most of State. Current total use of water about 1 billion gallons a day; about 850 million gallons used in a dozen areas of heavy development, about 70 percent ground water and 30 percent surface water. Water of good quality not abundant in some areas. General information available on most of State, but insufficient detailed data to form adequate basis for present and prospective future uses. State includes some of most productive limestone aquifers in the world.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Jacksonville-Fernandina area, Duval and Nassau Counties	Total draft about 90 million gallons per day, almost entirely from limestone aquifer. No overdraft.	Information on quality and availability of deeper water at Jacksonville.	Large additional supply available from properly spaced wells. Use of artesian water at Jacksonville may be doubled if studies show deeper water to be of good quality. Black Creek and St. Marys River available if needed.
Kingsley Lake area, Clay County	About 5 m. g. d. pumped for use in mining heavy minerals.		Large additional supply available from ground and surface water.
Hastings area, St. Johns County	Flowing wells used for irrigating truck farms, draft unknown.	Determination of draft and of yield from adequately spaced wells.	Large additional supply available if properly developed.
Sanford area, Seminole County	Water from 2,000 wells used to irrigate 7,000 acres of truck crops; draft about 15 m. g. d. Some water salty.	Occurrence of salty water, to determine whether salinity is increasing.	
Indian River area	One of areas where artesian water is salty, as is common in southern part of Florida Peninsula. Surface water and water from shallow aquifers used for public supplies; inadequate in places. Contamination by upward seepage of artesian water at Ft. Pierce and Stuart well fields. About 100 m. g. d. used for irrigation, mostly surface water.	Extent of salt-water contamination, availability of surface water, effects of drainage on quality and availability of surface and ground water, perennial yield of shallow aquifers.	Water supplies undoubtedly adequate, but only if properly developed on basis of better data than now available.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Southeast coastal area	Area of heaviest water use in State, and of most productive aquifers ever investigated by Geological Survey. Total use about 145 m. g. d., of which 120 m. g. d. is ground water. Use soon expected to be 200 m. g. d. Local problems of salt-water encroachment, floods, drainage, and pollution.	Comprehensive water-resources study made, continuing studies needed to guide design of projects to eliminate problems.	Water available to meet total expected demand and much more, if proper steps are taken. Projects are needed to control both floods and excessive drainage, to halt salt-water encroachment in and beneath drainage canals, and to eliminate pollution of Biscayne Bay by sewage. (Pollution control now under way.)
Miami area	Salt-water encroachment along shore, and via canal into principal well field in 1939 and later, due to excessive lowering of water table and reduction of canal flow by drainage.	Comprehensive study made.	Dams in tidal canals will keep water level up and prevent encroachment both in canal and beneath it in permeable limestone. New well field located for development as needed.
Everglades area	Ground water of good quality scarce. About 110 m. g. d. used in area, mostly from Lake Okeechobee and drainage canals. Lack of water in dry season, and floods in wet season, create complex problems. Overdrainage has permitted drying of muck soil and settling of as much as 6 feet in last 35-40 years.	Basic hydrologic data seriously lacking for design of control structures.	Ample water available but control is difficult and handicapped by lack of basic data.
Highlands area of central Florida	About 200 m. g. d. used, mostly for citrus growing and packing and phosphate mining; about 90 percent ground water. Principal area of recharge of artesian water of central Florida.	Data on recharge of artesian water and on relations of water at various depths, to determine how to obtain maximum yield with least drawdown.	Locate wells so as to avoid lowering levels of lakes, which would impair their moderating effect on temperature and permit more freezing of citrus groves.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Southwest coastal area	Water obtained mostly from wells. About 45 m. g. d. used for irrigation, mostly highly mineralized water from artesian wells. Public supplies from shallow wells and surface sources, about 6 m. g. d. Some salt-water encroachment along tidal streams.	Extent of salt-water encroachment, effects on ground-water levels of drainage and pumping, availability of water from streams, quality of water.	Adequate water available to meet expected needs, but available data insufficient for economical development.
Pinellas County	About 21 m. g. d. used in county, 11 from ground, 1 from streams, and 9 from wells in western Hillsborough County. Overdraft on ground water has caused salt-water encroachment along most of coastal part of peninsula, totaling about a fourth of its area. Lake Tarpon available but water salty because of underground connection with sea. St. Petersburg abandoned wells in 1930 and developed new well field in Hillsborough County.	Possibility of closing connection of Lake Tarpon to sea. Amount of ground water remaining for development in center of peninsula.	Water available from Lake Tarpon if connection with sea can be closed; in northwestern Hillsborough County and Pasco County; and, if necessary, Weekiwatchee Springs 25 miles to north.
Western Hillsborough County	Area closely related to Pinellas County. About 50 m. g. d. used in area, about 60 percent ground water. Salt-water encroachment along coast; Tampa wells abandoned and supply developed from Hillsborough River.	Potential yield of ground water under conditions preventing salt-water encroachment.	Ample water available to meet future needs, both surface and ground water. Ground water should be developed at sufficient distance from bay.
Pensacola area	About 35 m. g. d. of ground water used at Pensacola. Salt-water encroachment from Bayou Chico ruined old Naval Station well field and several industrial wells.	Stream-flow data for reservoir design as necessary. Further studies to guide development of ground water in such a way as to avoid salt-water encroachment.	Large additional ground-water supplies available if developed a mile or more from Pensacola Bay. Large surface run-off available also.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Panama City area	About 13 m. g. d. used, mostly by paper mill. Salt-water encroachment has ruined a few mill wells.	Availability of ground water under conditions preventing salt-water encroachment.	More water available, but only by dispersing wells widely and locating them sufficiently far from salt water.
Pollution problems	Pollution by untreated wastes of several inland lakes, lower stretches of St. Johns River and several other rivers, and shallow coastal waters in Nassau, St. Johns, Volusia, Brevard, Indian River, St. Lucie, Martin, Palm Beach, Broward, Dade (Miami), Lee, Charlotte, Sarasota, Manatee, Hillsborough, Pinellas, Citrus, Levy, Dixie, Wakulla, Franklin, Gulf, Bay, Walton, Okaloosa, Santa Rosa, Escambia Counties. Pollution of ground water in Suwannee, Marion, Orange, and Polk Counties by waste disposal through wells.		Adequate pollution-control measures to prevent danger to public health and adverse effect on tourist industry.
Floods	Everglades, Miami and other coastal areas; Kissimmee, upper St. Johns, and Suwannee River areas and Tampa area; and certain smaller areas are subject to flood damage, particularly during hurricanes.	More adequate surface-water data for design of control structures and bridge openings.	

Georgia

Large water resources available and largely undeveloped but limited in some areas of rapid industrial and municipal expansion. Only moderate flood damages and local pollution so far but potential danger with further development. Lack of basic data hampers planning. Among principal problems are limited ground-water supplies in Piedmont section; rapid growth of North Georgia industries and towns overtaxing water-supply and sewage-disposal systems; waste of flowing artesian water in Coastal Plain; potential salt-water encroachment along coast, especially in Savannah area; conflict between hydro-power and water-supply uses of low river flows; design of bridges across broad swampy flood plains; siltation of reservoirs and Savannah Harbor; lack of good reservoir sites and hydro-power in South Georgia and adjacent Florida; control of potential widespread pollution; potential flood danger in Coastal Plain as industry develops there to utilize abundant ground- and surface-water supplies and river navigation; agricultural supplies for supplemental irrigation and stock water; rural supplies adequate for electric-driven running-water systems.

Note: Estimates of water consumption include most domestic and municipal supplies but are very incomplete for industrial supplies.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Mountain and Piedmont areas of hard rocks	Moderate ground-water supplies available in many places but meager in much of Piedmont area; generally adequate for towns no larger than 2,500, or equivalent demand. Surface-water supplies available mostly by using small streams but require treatment plants and reservoirs. Estimated domestic and municipal use of ground water 34 million gallons per day; known use of surface water about 115 million gallons per day, including some of the manufacturing use.	Data on ground water to permit increased use; data on flow of small streams.	Large surface-water supplies available but reservoirs needed. Small streams with reservoirs will be main source of water for all but a few of the largest cities. Control of pollution imperative. Moderate ground-water supplies available if adequate studies are made to evaluate different types of rocks as aquifers. Erosion control on farms and roadsides essential to prevent siltation of reservoirs.
Northwestern area of Paleozoic rocks	Estimated domestic use of ground water 20 million gallons per day, of surface water 5 million gallons per day.	Data on availability of water from wells and springs; on stream flow.	Estimated 300 million gallons per day available from wells and springs. Large surface supplies available; reservoirs needed.
Upper Coastal Plain	Scarcity of shallow ground water for domestic supply in some areas. Domestic use of artesian water estimated 22 million gallons per day, of surface water 18 million gallons per day. Drainage and flood problems; 11 percent of lands subject to overflow. Potential pollution of streams.	Occurrence and potential yield of artesian aquifers; availability of "rejected recharge." Data on stream flow and potential power-dam sites.	Large undeveloped supply of artesian water - recharge area for lower Coastal Plain. Large surface supplies available because ground-water reservoirs provide natural equalization of seasonal flow. Potentially one of the finest sources of great amounts of best-quality industrial supplies; area lacks only transportation facilities for development.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Lower Coastal Plain	Estimated domestic and industrial use of ground water 150 million gallons per day, of surface water 6 million gallons per day. Much waste of flowing artesian water in low areas. No regional overdraft of ground water, but potential salt-water encroachment in Savannah area. Shallow ground water scarce in some areas. About 15 percent of lands subject to flooding. Scarcity of dam sites for power.	Safe yield of ground-water reservoirs, especially in coastal areas where overdraft may cause salt-water encroachment. Data on stream flow, especially of small streams. Information especially needed on flow in swamps in broad river bottoms and across deltas.	Large supplies of ground and surface water available if properly developed. Small rivers require large reservoir storage for development. Larger rivers, well regulated by ground-water storage in upper Coastal Plain, have abundant water but river swamps remain flooded for long periods. Extensive drainage, flood protection, and bridging needed.

Idaho

Idaho is a major contributor to streams originating in or passing through State. Surface water is largely appropriated or earmarked in many basins, however, and much irrigable land remains which must be irrigated with ground water, if at all. Irrigation mainly in southern part of State, less essential in north, which contributes much water used for power generation downstream. Data on ground water are grossly inadequate to determine areas of potential irrigation from wells, and of the effects on surface water so as to permit coordinated development and prevent both interference and waste. Potentialities are considerable, but basis for design and development is largely lacking. Data on quality of available water and changes caused by use are needed to evaluate life of existing and proposed projects. Estimated ground-water draft for irrigation within 2 to 5 years will be perhaps 4 million acre-feet, plus a large amount for other uses.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Kootenai River Basin	Flood-control problems. Coordination of present and proposed power developments with British Columbia, Washington, and Oregon. Little irrigation with surface water; most is "subirrigation" in areas of shallow water table. Excess ground water requires drainage.	Alternate means of flood control and utilization of water, especially for power generation, coordinated with downsteam users; effects of proposed projects upstream (Libby or alternative project); relation of river level and water table; sedimentation in river channel; continued observation of ground-water levels to guide drainage operations.	Coordinated development of surface water for different uses. Drainage of waterlogged areas, guided by adequate information.
Clark Fork-Pend Oreille Basin	Little use of surface water in Idaho, except for transportation of logs and for recreation. No important ground-water problems within surface drainage basin except determination of underflow from Lake Pend Oreille.	Possibility of increasing storage in Pend Oreille Lake; of adjustment of storage and flow requirements to recreational uses. Flow and slope of Clark Fork River for use in dam design, especially to permit comparison of flow and slope between Sandpoint and Albeni Falls before and after construction of Albeni Falls Dam. Data needed on flow of tributaries. General ground-water data needed, especially on quantity of underflow from Lake Pend Oreille to Spokane Valley.	
Spokane River Basin - Rathdrum Prairie	Flood threat above Coeur d'Alene Lake. Sedimentation and mining pollution of Coeur d'Alene River. Hayden Lake, which has no natural surface outlet, has just risen to highest stage of record, and bordering recreational property is being damaged. Present ground-water development largely for domestic and farm supplies.	Studies of alternate means of flood control and water utilization. Determination of present ground-water flow into Spokane River and of probable changes caused by proposed new irrigation project on Rathdrum Prairie and by increased storage in Pend Oreille Lake, in relation to power and irrigation uses downstream. Intensive study of relations of ground and surface water and of hydrologic regimen as a whole.	

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Clearwater River Basin	Flood and sedimentation problems. Few large ground-water developments. Overdraft in Moscow area; interference between uses in same aquifers in Idaho and Washington. Lewiston and some other towns have had trouble in getting enough water.	Basic data on surface water to guide existing and proposed developments are very meager. Information need on ground-water resources of whole basin. Palouse Basin promising for research on relation of ground-water levels to stream flow, for predicting low flows. Local quality-of-water studies needed.	Possible undeveloped sources in or near Moscow area. Ground-water potential considerable but largely unknown.
Salmon River Basin	Relatively little development in basin; about 100,000 acres irrigated.	Opportunities for research on some relations of runoff to geology and topography, precipitation, temperature, and vegetative cover in a major basin little affected by regulation. Data needed on ground water in Lemhi and Pahsimeroi Valleys, especially if surface-water irrigation is developed as proposed. General ground-water studies needed in main part of basin to determine potentialities; detailed studies needed in local areas.	Possibilities for intermountain diversions to other basins. Several plans proposed, but only reconnaissance studies made so far.
Weiser River Basin	About 40,600 acres irrigated, about a third needs supplemental water. Additional land susceptible to irrigation. Development difficult because of scattered irrigated and irrigable acreages. Difficulty in obtaining adequate ground water in places, as for City of Weiser.	Additional stream-flow records and reservoir-content data to facilitate distribution of water for irrigation. Possibility of furnishing additional water for new or inadequately irrigated lands (considerable studies made by Bureau of Reclamation). Study needed to determine ground-water potential, relation of potential pumping to reclamation of wet lands, etc.	Additional surface- and ground-water development appears to be possible if adequate studies are made.
Payette Basin	Need for adjustment of water rights in connection with proposed increased irrigation and exportation of water to Boise Basin. Waterlogging in lower Payette Valley. Adjustment of storage in Payette Lake to fit increased recreational use. Balance between surface-water and ground-water uses.	Additional stream-flow records to guide reservoir operation, water "routing," runoff prediction; more accurate data on reservoir content. Thorough ground-water study.	Pumping to relieve waterlogging and permit increased irrigation. Considerable increased development of surface and ground water possible if done on basis of better data than now available. Large diversion to Boise Basin being considered.

Idaho - Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Boise River Basin	Boise River essentially fully used for irrigation, additional water needed, even in average years. Extensive waterlogging from irrigation. Sedimentation of Arrowrock and Lucky Peak Reservoirs and river channel above Eagle.	Comprehensive ground-water study needed to determine feasibility of drainage and supplemental irrigation by pumping from wells.	Available data indicate substantial part of water needed can be obtained by pumping from wells, which would also lower water levels and relieve waterlogging. Diversion of surface water to Mountain Home district considered; to be replaced in part by diversion from Payette Basin.
Snake River Basin	Large basin of diverse geologic and hydrologic characteristics. Can be divided into Upper and Central Basins at Milner Dam, above which appropriation is so complete that in time of low flow only enough water passes dam to meet downstream power rights.	Forms large and complex hydrologic unit in Idaho and adjacent States in which basic data are scattered and greatly inadequate to guide maximum use and equitable allocation of water. Surface water and ground water cannot be considered separately.	Integrated development of whole basin based on hydrologic studies of which only a small fraction have been made. Following discussion gives only a piecemeal idea of complexity of problem and need for data.
Upper Basin in Idaho (downstream to Milner Dam)	About 1,175,000 acres irrigated; total diversion in 1949 irrigation season 7,540,000 acre-feet. Six reservoirs store 2,872,000 acre-feet. Industrial uses small, except for power. Additional storage needed for proposed increased irrigation. Problems include interstate division of water with Wyoming, segregation of natural and stored water, possible interference between surface-water and ground-water uses, and allocation of water within basin. Additional water needed in Lost River-Beaver Creek district. Lack of sufficient over-all supply for Mud Lake-Beaver Basin; interference between ground-water and surface-water uses. Water needed for Central Lava Plain, now used mostly for grazing. Critical need for more irrigation water in Raft River Valley. Shortage of surface water for good arable land in Goose Creek and Salmon Falls Creek Basins; conflict with	Additional stream-flow data for operation of Palisades and Hoback Reservoirs and for operation of compact. Additional snow surveys for prediction of runoff. Ground water in Henrys Fork and Teton Basins. Stream-flow data to determine contribution from stream to ground water in Lost River-Beaver Creek district. Detailed ground-water study of entire Lost River-Beaver Creek district; availability of ground water at economical depth. Depth and availability of ground water beneath Central Lava Plain; relation to surface water of proposed Minidoka and other developments. Additional stream-flow data for Blackfoot-Portneuf district, including effect on return flow of increased irrigation at Fort Hall and Michaud. Relation of ground water in Raft River Valley to Lake Walcott. Possibility of ground water use in Goose Creek Basin to relieve shortage of surface water.	Palisades Reservoir and Hoback Reservoir in Wyoming proposed for storage of 1,400,000 and about 1,250,000 acre-feet, respectively. Upper Snake River Compact approved by Idaho and Wyoming. Minidoka North Side Pumping Division and private users plan to pump up to 600,000 acre-feet per year. Increased irrigation in Blackfoot-Portneuf district should be controlled so as to interfere as little as possible with downstream uses, yet reduce or prevent waterlogging. Increased storage in Raft River Valley; integrated development of ground water and surface water.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Upper Basin in Idaho (downstream to Milner Dam (continued)	Nevada interests over water rights. Shallow ground water polluted by underground sewage disposal at Burley, Rupert, and many other localities.		
Central Basin (Milner Dam to Hells Canyon dam site; excluding tributary Boise, Payette, and Weiser Basins, treated separately).	Irrigation along main stem small so far; power use extensive and increasing. Superimposition of proposed on existing projects will create difficult problems of management and allocation of water. Surface water fully appropriated in Wood River Basin; additional water needed; interference between surface-water and increasing ground-water use. Surface water rather fully appropriated in Twin Falls district and ground-water use increasing; interference between wells and with surface water; interstate rights; waterlogging from irrigation, especially in South Side project. Water needed for extensive unreclaimed lands in Mountain Home district; waterlogging will occur as soils are tight. Similar problems in Grand View-Bruneau district in connection with proposed Bruneau project. Problems of water shortage, waterlogging, drainage, etc., in parts of Owyhee Basin in Idaho similar to those in Payette and Boise Basins.	Availability of water for large unreclaimed areas between Milner and Weiser. Effect of proposed power, flood-control, and reclamation projects on present projects. Data for operation of Snake River Compact. Relation of Magic project to others proposed in Wood River Basin; extent of interference between surface-water and ground-water uses. Characteristics of aquifers in Twin Falls district and proper well-construction methods. Feasibility of ground-water pumping and other drainage methods to prevent waterlogging in Mountain Home project. Same for Bruneau project and Owyhee Basin.	Proposed irrigation developments include 400,000-acre Bruneau project and 380,000-acre Mountain Home project. Carey Reservoir on Little Wood River being enlarged. Ground-water development may be possible in parts of Wood River Basin to relieve surface-water shortage. Same in Twin Falls district, but complicated by low yields of wells. Proposed first unit of Mountain Home project involves diversion from Boise Basin for 230,000 acres, to be replaced in part by water from Payette Basin. Operation of entire Mountain Home project to avoid waterlogging; same for proposed Bruneau project. Ground-water pumping may be more economical or otherwise preferable to surface-water use in parts of Bruneau project.
Malad-Deep Creek District	Drains to Great Basin. Considerable ground-water development in Malad Valley but probably no overdevelopment. Severe shortage of surface water in Deep Creek Valley. Shallow ground water not abundant. Possible interference between ground-water and surface-water uses; interstate aspects.	Comprehensive ground-water studies in whole district, especially in Deep Creek Valley to determine availability of deep water, and to determine relation of surface water to ground water. Data for control of artesian wells and underground migration of water in Malad Valley.	Efforts to seal Elkhorn Reservoir continuing. Samaria Reservoir No. 2 and Deep Creek Reservoir No. 2 completed recently. Additional small reservoir units proposed on Malad River tributaries.

Idaho - Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Bear River Basin	Drains to Great Basin in Utah. About 1,000,000 acre-feet per year used in Idaho, Wyoming, and Utah, but about 750,000 acre-feet per year wastes to Great Salt Lake in floods. Controversy among States on water rights.	Comprehensive water-resources inventory; basic data of all types very meager.	Additional storage to prevent flood waste and dry-season shortage; interstate compact. Integrated development of both surface water and ground water.

Illinois

Over-all water resources adequate and capable of large additional development. Problems of local shortages, flood control and routing, pollution, and reservoir sedimentation. Ground water scarce in southern part of State for substantial uses, except locally. Coordinated study of interstate aspects of deep aquifers of northern Illinois and southern Wisconsin eventually may be needed. State Water and Geological Surveys have made extensive ground-water studies and are actively pursuing systematic programs. Surface-water data needed for some of smaller streams.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Drainage and flood control	Widespread and increasing problems, due in part to encroachment of growing cities on river flood plains, and restriction or lack of maintenance of channels.	Studies of effect of city growth in decreasing infiltration and increasing rapidity of runoff. Studies of flood routing.	Increase in channel capacities as needed to compensate for increased runoff; prevention of encroachment on channels. Systematic, continuing program of channel maintenance.
Stream pollution	Pollution by domestic and industrial wastes in a number of heavily populated areas. Financing municipal treatment works is a major problem.	Studies of extent and effect of pollution and methods of reducing it; being made by State but hampered by lack of funds and personnel.	Public education on necessity of control; making rapid progress. A number of industries have made substantial progress in alleviating pollution by industrial wastes.
Reservoir sedimentation	Many municipal reservoirs have lost a substantial part of their capacity.	Studies of extent of sedimentation and methods of erosion control (being made by State).	Problem receiving increased recognition. Need for erosion control and for increasing reservoir capacity for a given size of drainage area.
Ground water for municipal use	A number of cities, as demand has increased beyond capacity of local ground-water sources, have shifted from early ground-water to surface supplies for public use, including Springfield, Bloomington, Decatur, and some smaller cities and towns.	More data on availability of ground water, to determine whether additional development might be more economical than surface-water development; being gathered by State agencies in State-wide ground-water studies and in detailed studies of problem areas.	
Northeastern Illinois, including Chicago and Joliet areas	Chicago and some 59 other municipalities in metropolitan area obtain water from Lake Michigan, but many industries in Chicago and some suburban municipalities use ground water, approximately 23 percent from shallow limestones and glacial drift and 77 percent from deep aquifers, chiefly Galesville sandstone. Deep aquifers had large initial yields but appear to be of only moderate permeability, and heavy pumping is at expense of withdrawal from storage. Nonpumping levels, formerly near	State agencies have been actively studying this area since 1942, greatly extending previous studies; will result in quantitative appraisals of safe potential yields in the areas of heavy development.	The economics of deep pump settings, a discouraging factor in further ground-water development, is stimulating a shift from ground water to lake water. The effect on lake level probably will be negligible. However, increased withdrawals, if any, from the lake for sewage dilution in the Des Plaines and Illinois Rivers may require interstate and international agreement.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Northeastern Illinois, including Chicago and Joliet areas (continued)	the ground surface, are now from 300 to 450 feet below it, but still 850 to 1,000 feet above the top of the Galesville sandstone. Increasing depths of pump settings by reason of cost are discouraging further ground-water development in the local heavily pumped area and encouraging an increasing use of Lake Michigan water. Some aquifers tapped in southeastern Wisconsin and to a smaller extent in Northwestern Indiana; potential interstate problem but negligible so far.		
Peoria area	Local overpumping reported.	Studies to determine ground-water potential outside area of heavy pumping, and also the practicability of artificial recharge and "induced infiltration" potentiality of Illinois River (extensive studies being made by State).	Available data suggest that Illinois River may recharge water-bearing gravels substantially; thus, additional water might be obtained by locating wells nearer river.
Champaign-Urbana Area	Former local overpumping largely remedied by development of new ground-water sources outside city, based on extensive studies by State.		
East St. Louis Area	Local overpumping reported, but water table not yet depressed enough to induce large-scale infiltration from Mississippi River.	Detailed geologic and hydrologic study of alluvial materials with respect to river-infiltration possibilities; under way by State.	Large additional supplies probably available by induced infiltration from Mississippi River, or from wells located away from present areas of heavy pumping.

Indiana

No serious over-all shortage of water. Some local problems of shortage, many of which are due more to economic than to hydrologic factors. Problems of flood control and prediction, hydrologic factors in bridge design, and pollution of streams and local pollution of ground water. Present water use, exclusive of power production, estimated at 660 million gallons a day, 275 surface water and 385 ground water. Large increased use possible in most areas, but basic data inadequate for locating additional supplies to meet deficiencies and provide for increased use. Data on quality of water and sedimentation especially meager. Largest ground-water supplies available in northern two-thirds of State.

Area or subject	Current situation	Deficiencies in information	
Flood control	Flood problems exist in practically all basins of State, especially serious in Wabash and White River basins. Lack of data on flow of small basins hampers proper bridge and culvert design and erosion-control activities.	Data on flow characteristics and maximum discharge relations under various levee conditions are inadequate. Studies of major basins under way by Army Engineers and of minor basins by Indiana Flood Control and Water Resources Commission. Data on flood flows and flow characteristics of small basins inadequate.	
Pollution	Widespread pollution of streams and some lakes. Local pollution of wells.	Extent of pollution and methods of abatement, especially for treating industrial wastes for public-health and recreational needs; situation not known. Areas of ground-water pollution not determined. Pollution of major streams and basins being studied by Indiana Pollution Board and State Board of Health.	
Public water supply	Generally adequate. Lack of known additional supply hampers municipal and industrial growth in many localities, especially those dependent on ground-water supply. Original development generally not based on adequate study of hydrologic factors. Critical shortages at Bloomington and potential shortages and pollution problems in Muscatatuck River Basin. Potential ground-water shortages at New Castle, Elwood, and many others.	Information on surface-water supply generally adequate except for small basins, many of which are used for municipal supply. Data on extent, recharge, and perennial yield of ground-water reservoirs inadequate. Detailed ground-water studies needed to determine adequacy of local sources which supply 281 of 323 municipal systems and 92 of the 260 million gallons a day used for municipal supply.	Storage reservoir considered for Bloomington. Reservoir needed for Muscatatuck Basin.
Industrial ground-water supply in general	Few serious shortages reported. Many industries unable to locate in otherwise desirable areas because of lack of assurance of adequate water supply.	Data on safe yield of ground-water reservoirs inadequate; needed to encourage industrial growth.	Large supplies available but must be developed on basis of data yet to be gathered, to prevent overdevelopment.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Quality-of-water and sedimentation problems	Serious lack of data on quality of water and suitability for various uses. No sedimentation studies under way.	Chemical quality-of-water data needed generally, especially in southwestern part of State. Sedimentation studies needed especially in Wabash, White, Maumee, and St. Joseph basins and in small basins in southern part of State. Quality-of-water data now being collected as part of ground-water investigations.	
Indianapolis area	Present supply for Indianapolis adequate; more surface storage or greater use of ground-water storage necessary for future growth of city. Ground-water situation critical in 1941 but has improved since, owing to reduced consumption and increased precipitation. Ground water used mainly for industrial purposes.	Revised estimate of perennial yield; relation of pumping to flow of West Fork of White River. Investigation of ground-water supplies in residential fringe area of Marion County now in progress.	

Iowa

No over-all shortage of water, but numerous problems of flood control, drainage, inadequacy of water in dry periods, pollution, and sedimentation. Local critical shortages of surface and ground water. Basic data inadequate. Only cities on Mississippi and Missouri Rivers have assurance of large surface-water supplies without building storage reservoirs. Estimated total use of ground water 340 million gallons a day, moderate to large additional supplies available outside heavily pumped areas in northeastern two-thirds of State and along Missouri and Mississippi Rivers. No estimate of surface-water use available.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ground-water shortages	Water levels down to critical point in shallow aquifer at Cedar Rapids. Decline at Mason City; situation may become critical. May become critical also at Oskaloosa.	Safe yield of aquifers used at present; potential additional supplies.	Deeper aquifers available at Cedar Rapids but wells more expensive.
Surface-water shortages and pollution	Inadequate water in streams during period of low flow to provide sufficient water supply and dilution of polluting materials. Situation critical at Ottumwa, Mason City, Waterloo, and Fort Dodge; serious at Des Moines, Ames, and Cedar Rapids. Similar situations may develop in any city of 10,000 or more in next few years.	Additional stream-flow data to determine dependable yield of basins and to guide reservoir design, pollution control, water use and conservation, flood control, and bridge design.	Storage reservoirs needed to permit increasing low flow; size and cost will depend on extent of pollution abatement found practicable. Des Moines infiltration gallery depends on Raccoon River, supplemented by artificial recharge. Possibly other cities could make similar developments.
Flood and sediment problems	Acute flood problems on Indian Creek at Council Bluffs, Des Moines River below Des Moines, Black Hawk Creek and Cedar River at Waterloo, Perry Creek at Sioux City, Iowa River and tributaries at Marshalltown, Iowa River below Iowa City, and Boyer, Chariton, and Grand Rivers, among many others. Problem complicated by deposition of silt in channels.	Studies to determine most economical methods of flood and sediment control. Additional sediment data.	Erosion and sediment control. Soil Conservation Service has begun large soil-conservation project in Little Sioux Basin.
Southern Iowa	In roughly southern two tiers of counties productive shallow aquifers are generally absent and base flow of streams is therefore low, causing shortage of water in period of low flow, especially in drought years. Deeper aquifers not adequately tested.	Careful study to locate all potential sources of ground water. Surface-water studies to locate sites for reservoirs.	Increased surface-water storage based on most economical design.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Western Iowa	Productive aquifers largely absent beneath uplands and in small valleys. Shallow aquifers of low permeability more widespread than in south, however, and base flow of streams more adequate.		

Kansas

Precipitation increases from west to east; productive water-bearing formations mainly in west and lacking in much of east. Thus surface runoff is relatively high in east, but low flows poorly sustained and many problems of alternating flood and shortage, and erosion and sedimentation. Ground water relatively abundant in west, but recharge low in High Plains uplands. Only one area of ground-water shortage in State at present, and greatly increased development possible, but it should be guided by proper estimates of optimum yield. Much increased development of surface water possible; storage needed in most cases. Basic data reasonably adequate for substantial part of State but investigative program far from complete. Ground-water and sediment studies needed to guide irrigation and sediment control. Stream-flow data especially lacking for south-central and southwestern parts of State.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Southeastern Kansas	Water of good quality from deep aquifer but perennial supply probably less than current withdrawal. Aquifer extends into Oklahoma and Missouri; interstate problem. Aquifer similar hydraulically to Dakota sandstone. Problem of drainage of mines in shallower water-bearing limestones.	Quantitative appraisal of aquifer as a whole in the three States. Availability of water from other sources.	Gradual reduction of draft on basis of interstate agreement, development of other sources as necessary. Water available in shallower limestones but quality not as good; may be useful for some purposes.
High Plains	Much water in storage and many productive wells. Recharge low, however, though higher than in Texas; problem of determining how to utilize stored water.	Determination of perennial yield and yield from storage under various conditions of development.	Development of water to produce maximum benefit for longest time.
Arkansas Valley	Abundant ground water, but of poor quality between Great Bend and Arkansas City.	Studies to determine how maximum amount of water of good quality can be developed.	
Saline and Republican Valleys	Ground water highly mineralized in places.	Studies as above.	

Kentucky

Over-all water supply adequate. Many problems of alternating flood and shortage. Ground water scarce in much of State, and data scanty except in a few small areas. Inventory of present and prospective demands is necessary.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ohio River flood plain	Large surface supply available from Ohio River, and large undeveloped ground-water supply from valley fill beneath plain. Total municipal use about 85 million gallons per day, about 81 surface water and 4 ground water. Total industrial use unknown, but more than 50 million gallons per day of ground water and more than 600 million gallons per day of surface water (greater part for steam-power generation). River badly polluted; too warm in summer for many industrial uses. Flood damage serious along main stem.	Availability of ground water along river, mainly by "induced infiltration." Studies of pollution and flood control.	Greatly increased use of ground and surface water possible. Reduction of pollution needed, and gradually getting under way by cooperative efforts of States and industries in basin. Development of ground water by induced infiltration promising, as water is cooler in summer even though derived largely from river. Passage of water through river bed and ground appears to remove pollution. Flood control by construction of reservoirs on tributaries and protection structures on main stream.
Louisville area	Ground-water situation critical early in war; improved greatly by cooperative emergency effort after safe yield of existing installations determined by comprehensive study. Treatment and use of Ohio River water still complicated by pollution.		Large additional ground-water supplies shown to be available northeast and southwest of city by induced infiltration.
Jackson Purchase (area west of Cumberland River)	Rapid industrial expansion expected, due to cheap power and river transportation. Need for cool water for industrial use will increase rapidly. Land-drainage and flood-control problems due to flat surface. Municipal use of ground water is 5 million gallons per day, of surface water(Paducah), 3 million gallons per day, industrial use unknown.	Comprehensive study of ground -water resources. Data on flow of small streams, and on quality and sediment content of water.	Large supplies of surface water available, but cool water needed in summer. Large ground- water supplies known to exist, but almost no data on occurrence, quantity, and quality.
Plateau of Mississippian rocks in central, south-central, and west-central Kentucky	About 4.5 million gallons per day of surface water used for 24 towns and 1 million gallons per day of ground water for 21 towns. Industrial use small but increasing. Ground water scanty in some areas, as is low flow of streams away from main stems. Flood problems along lower Cumberland River.	Availability of ground water for small industries and towns. Data on flow of small streams, especially in Green River Basin. Data on quality, temperature, and sediment load of streams.	Large supply available along Ohio River. Moderate to large ground-water supplies available in some areas underlain by limestone.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Western coal field	About 2 million gallons per day of surface water used for 14 towns and 1 million gallons per day of ground water for 9 towns. Industrial use not known. Small quantities of artesian ground water widely available but large supplies scarce. Decline of water level at Beaver Dam. Care needed to avoid pollution of ground water by oil-field wastes; water needed for repressuring. Flood and drainage problems, and dry-season shortage of surface water.	Availability of ground water and dependable yield with different well spacings. Methods of underground disposal of oil-field wastes without polluting usable water. Data on flow of small streams and quality of water.	Wider spacing of wells at Beaver Dam; possible ultimate use of surface water, now beyond economic reach. Considerable additional development of ground water and especially surface water possible if planned on basis of sound data. Large water supply available along Ohio River.
Bluegrass region of northeast-central Kentucky	Municipal use of water 13 million gallons per day of surface water for 34 towns and 1.5 to 1.75 million gallons per day of ground water for 14 towns. Most ground water used is from springs. Industrial and rural use not known but fairly large. Supplemental irrigation from wells probably will increase greatly. Ground water in outer part of region scarce and poor in quality; supplies for stock raising difficult to obtain. Water in limestone of inner Bluegrass region erratic in occurrence and subject to pollution in places. Problems of stream pollution, shortage in dry periods, and some flooding.	Occurrence of ground water in outer part of region. Data on flow of smaller streams, pollution and methods of flood control.	Ground-water study in inner Bluegrass region showed close correlation among geology, topography, and water, and has greatly increased chances for obtaining successful wells. Similar study needed in outer region, where conditions are even more spotty. Large supply available along Ohio River.
Eastern coal field	About 5 million gallons per day from streams and 2 million gallons per day from wells used for public supply. Industrial use not known but substantial, especially for coal industry. Local shortages of ground water with increasing population of towns; Corbin and London have abandoned wells in favor of surface water. Low ground-water storage leads to flash floods and low flow in streams in dry weather. Pollution of streams, especially at low stages.	Ground-water studies to encourage maximum economical use of this resource. Stream-flow data for design of flood-control and flow-stabilization reservoirs. Data on quality of water, extent of pollution, and silt load.	

Louisiana

Very large supplies available from large rivers: Mississippi, Atchafalaya, Red (quality poor), Pearl, and Sabine Rivers, and from ground. Main problems are flood control, drainage, and dry-season shortage of surface water, and some local and even regional overdevelopment of ground water. Total ground-water use estimated to be more than 800 million gallons per day. Basic data inadequate for economical planning of water control and use. Little or no ground water of good quality available in small area in west-central part, in extreme southern part, and in some areas in northwestern part of State.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Southwestern Louisiana	Seasonal pumping from surface streams to irrigate rice lands exceeds natural flow during periods of below-normal runoff. During these periods, salt water intrudes into the streams and causes crop losses of greater or less degree. About 660,000 acre-feet of surface water was used in 1949. Ground water is used to irrigate nearly half the total acreage under rice cultivation; withdrawals amount to 400,000 to 600,000 acre-feet per year. Ground-water levels declining; salt-water encroachment believed occurring.	Comprehensive water-resources investigation (now under way) should be continued to give factual data required for alleviating works to be constructed on surface streams and determination of maximum yield of ground water without salt-water encroachment, and to guide necessary measures for assuring adequate over-all supply.	Storage or diversion to save flood waters now wasted to Gulf and assure dry-season availability of water, to meet present deficiency and future needs, and to permit reducing ground-water withdrawal to safe yield. Artificial recharge if feasible.
Lake Charles area	Ground-water withdrawal increased from 2 million gallons per day in 1935 to 60 million gallons per day in 1949. Local overpumping. Pollution of surface water.	Detailed water-resources investigations as above. Extensive and continuous records on quality of water.	Wells can be distributed to avoid local overpumping, but question whether combined draft for industry, public supply, and rice irrigation may be in excess of safe limit. Pollution abatement may be necessary. Artificial recharge if practicable.
New Orleans area	Public supplies from Mississippi River. Air-conditioning and industrial pumpage from wells is 50 million gallons per day or more. Water level declining. Possible salt-water encroachment. Drainage and flood-control problems.	Study to determine maximum rate of pumping without inducing salt-water encroachment from Mississippi River or other sources.	Holding ground-water withdrawal to safe yield. Spreading wells and development of new areas would possibly increase yield. Artificial recharge if practicable.
Norco area	Ground-water draft of 20 million gallons per day for oil refining. Declining water levels; salt-water encroachment possibly occurring.	Detailed ground-water study as above.	As above.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Baton Rouge area	Ground water is main source for public and domestic uses and a large source for industrial use; much river water used for industry in winter. Ground-water pumpage about 70 million gallons per day. Water levels in "shallow" sands declining, locally overdeveloped in industrial district.	Availability, quantity, quality, and temperature of water from deeper aquifers and Mississippi River alluvium.	Large supplies available from deeper aquifers but water warmer. Large supplies of cool but hard water available from Mississippi River alluvium, but principally across river from Baton Rouge. Possibility of making greater use of Mississippi River and Comite River waters.
Other declines in ground-water levels	Water levels declining at Springhill, Minden, Hodge, Monroe, Bastrop, Alexandria, and Elizabeth. Areas not definitely known to be overdeveloped.	Comprehensive water-resources investigations to determine safe yield of known aquifers, possible occurrence of other fresh-water-bearing sands, and possible utilization of additional surface-water supplies.	Water probably available outside areas of decline if developed properly.
Southeastern Louisiana	Waste of water from flowing artesian wells (estimated 35 million gallons per day in St. Tammany Parish alone). Much water used for strawberry irrigation and public supply. No serious problem at present.	General study of water resources.	Very large supply of soft ground water appears to be available but needs evaluation. Waste of flowing artesian water, though it has not caused overdevelopment, should be reduced. Large supplies of good surface water available.

Maine

Abundant over-all water supply, with capacity for greatly increased development. Three-quarters of State forested and very lightly populated. Probably something less than 10 million gallons per day of ground water used by some 65 public systems and more than 80 million gallons per day of surface water by about 95 systems; total of 201 communities served. Few data on other uses of water. Some problems of pollution and flood control, and local or dry-season shortages of water for smaller users. Almost no ground-water information available for State.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Stream pollution	Most of main rivers show some pollution. Androscoggin, Penobscot, and Kennebec Rivers are among most serious. Presumpscot River excessively contaminated below Westbrook and Saco River heavily contaminated below Biddeford and Saco.		Pollution control began on Androscoggin as result of legal action. Bangor on Penobscot and Richmond on Kennebec have had to build elaborate treatment plants to obtain good water for public supply, and Richmond is seeking a new supply. Additional pollution control necessary.
Floods	Floods are not a serious problem in most areas, partly because of regulation of rivers by reservoirs built for power production. Greatest flood on record, in 1936, caused damages of about $6,500,000. Problems will increase with growth of population on land subject to overflow.		Flood walls built at Madison and Rumford by private interests.
Ground-water supplies	Ground water used on only a small scale so far. The few studies made so far, at Bangor, Lewiston and Auburn, and Portland, show no overdevelopment, and the few observation wells show no decline. Ground water is locally scarce, as at Corinna where surface water is polluted and test drilling for ground water has been unsuccessful so far.	General ground-water study of whole State.	Large ground-water supplies probably available in places, principally glacial outwash gravel in valleys and plains of south slope. Adequate studies needed to locate productive aquifers and so to encourage development, and to provide basis for preventing overdevelopment. Town of South Paris has located an ample supply of ground water; Clinton supply adequate. Artesian water known to be available at Portage and Presque Isle. Abundant ground-water supply located at Patten, for future use.
Farm water supplies in general	Shortages common in dry weather.		Development of more adequate supplies, particularly for fire protection. Many ponds now being built for this purpose. Ground water a promising source in some areas, but information lacking.

Maryland

No over-all shortage of water. Total use of ground water about 100 million gallons per day, of fresh surface water about 400 million gallons per day (about 90 percent for Baltimore and Washington); plus about 500 million gallons per day of brackish water from Patapsco River for industrial use in Baltimore. Problems are chiefly economic, requiring careful study to find most economical solution, and basic data on stream flow, ground water, and quality of water are far from adequate.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Appalachian area (western third of State)	Total use of water small, but shortages occur in dry weather because of low ground-water storage; streams "flashy".	Data on ground water and stream flow.	Increased development of ground water where possible; storage reservoirs on streams as needed.
Piedmont Plateau	Ground water widely available in small quantities, but no large supplies. Soil erosion in many farmed areas and streams generally turbid.	Research on occurrence of water in the complex rocks, to determine whether criteria can be established for more successful location of thousands of farm and suburban wells	Soil-conservation practices needed in some areas.
Coastal Plain - Western Shore	Ground water moderately to highly developed from Baltimore northeastward, with some overdevelopment. Iron content of ground water high in some of the area.	Basic studies of ground water (under way in practically the whole area).	Large ground-water supplies available outside heavily pumped areas but potential yield not known for entire area. Supplemental irrigation from wells promising if done on basis of adequate data.
Baltimore area	Local overpumping; encroachment of salt water from Patapsco River in large part of area, of industrial waste in places, largely through defective wells. Few major well fields free of contamination. Total ground-water withdrawal 50 million gallons per day or more in 1942; now 35 to 40 million gallons per day. Public supply from Gunpowder Falls; safe yield of 148 million gallons per day exceeded (190 million gallons per day in 1949).	Comprehensive ground-water study completed.	Repair of wells, spreading of pumpage as practicable. Tunnel from Patapsco River nearing completion; will add 50 million gallons per day to public supply; or 95 million gallons per day when proposed reservoir is built. About 35 million gallons per day of sewage effluent treated for industrial use to permit reduction of draft on contaminated wells.
Washington suburban area	Development of suburban water supply, from Patuxent River and Northwest Branch of Anacostia River, is barely keeping pace with demand. Anacostia River water polluted.		Rocky Gorge dam on Patuxent River, to be completed in 1953, will increase total supply to 40 million gallons per day. Anacostia River supply may be abandoned. Consideration being given to larger sanitary district including Ellicott City, Annapolis, Upper Marlboro, and Rockville; available water from Patuxent and Little Patuxent possibly about 150 million gallons per day.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Coastal Plain - Eastern Shore	About 20 million gallons per day of ground water used for public and domestic supplies. Streams small and many brackish in lower courses. Ground water high in iron in many places.	Basic ground-water studies (now under way in parts of area).	Large additional ground-water supplies available if properly planned and located on basis of adequate data. Supplemental irrigation from wells especially promising.
Crisfield	Ground water of poor quality.	Availability of better water; analysis of available data.	
Ocean City	City taking maximum amount available with present pumps and wells.	Pumping tests and other studies to determine yield of the 13 individual wells and of the different water-bearing formations.	
Cambridge	Salt-water contamination through leaky wells.	Detailed study to determine levels at which salt water enters wells.	Reconstruction of wells to exclude salt water; location of new wells if necessary to avoid contamination.
Easton	Municipality and industries derive water from five aquifers ranging in depth to as much as 1,188 feet.	Detailed study to determine quantity taken from and safe yield of each aquifer.	
Pocomoke	Uncertainty as to adequacy of present supply.	Yield and drawdown of present wells; pumping test of new wells.	
Pollution and sediment problems	Potomac River polluted by acid mine drainage, industrial waste, and sewage in Luke-Cumberland area, and by sewage at Washington. Monocacy River carries silt from soil erosion. Patapsco River contaminated by industrial waste.	Studies of pollution and silt control (under way for Monocacy River).	

Massachusetts

Water available to meet practically any need, but economic factors limit some of smaller developments. Almost all water soft (hard ground water in western limestone belt); ground water generally corrosive and some high in iron, especially on Cape Cod and in northeastern Middlesex County. No silt problems. Some drought and flood problems. Ground water available principally in glacial deposits throughout the State, especially in eastern, southeastern (including Cape Cod and nearby islands), and west-central (Connecticut Valley) parts of State; in bedrock in extreme western part and in parts of Connecticut Valley. Bedrock furnishes small supplies for domestic use throughout the State. Among basic-data needs are flow of small streams, ground-water studies including test drilling and geophysical studies and determination of safe yield, and quality data for industrial and pollution-control uses.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Public and industrial supply	In 1948, of 260 public systems serving 98 percent of population, 150 used 100 million gallons per day of ground water and 110 used 300 million gallons per day of surface water. About 100 million gallons per day of ground water used by industry, and unknown but much larger amount of surface water by industry.	Considerable data available; more needed.	Much additional water available, but studies needed to locate unpolluted sources that can be developed economically.
Pollution	Serious problem of stream and tidewater pollution. About 320 million gallons per day of treated and untreated sewage discharged (300 into tidewater near Boston), plus much industrial waste.	Problem under study by several agencies.	Streams being classified by State Public Health Department. Pollution-control measures under way or being studied.
Salt-water encroachment	Not a serious problem at present. Occurred in one public-supply well field on Cape Cod and also reported in one or more cranberry-irrigation areas.		Development of ground water near coast in accordance with local hydrologic conditions (not completely known for Massachusetts) and known physical principles of fresh water-salt water relations.
Droughts	Shortages common in smaller towns with less adequate supplies. Occurred in 44 of 260 communities having public supplies in 1949-50.		Problems are economic or due to lack of planning. In both cases more adequate basic data may permit a satisfactory solution.
Ground-water depletion	No general decline of ground-water levels. Many shallow wells failed in last 2 years because of drought.		In most cases deeper wells have given adequate supply.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Floods	Floods in 1927, 1936, and 1938 affected 36,000 acres and caused damage of about $112,000,000.		Local protection works constructed at Springfield, West Springfield, Holyoke, Chicopee, Northampton, Haverhill, Lowell, and Fitchburg; in progress at Adams and North Adams. Three flood-control reservoirs built in State; one in Vermont and four in New Hampshire on streams tributary to the Connecticut and Merrimack Rivers above Massachusetts line; 21 more scheduled for future, mostly in Vermont and New Hampshire.
Supplemental irrigation	Practice is growing - 2,049 acres in 1939 and 11,355 acres in 1944.	Studies to determine availability of the relatively small supplies needed, and to prevent local over-development.	Practice has much promise. Either surface water or ground water can be used, depending on which is available or cheaper.
Water power	Largely developed - reported total 245,700 kilowatts. No new large reservoir sites available. Present storage reported at 8,200,000,000 cubic feet.		Undeveloped power variously estimated at 18,000 to 106,500 kilowatts.

Michigan

Nearly surrounded by the Nation's largest fresh-water lakes, Michigan is often erroneously considered free of water problems. State has enormous water potential, but there are local problems of ground-water overdevelopment; stream and ground-water pollution; undesirable lake-level fluctuations; and floods and drainage. Moderate to large ground-water supplies available generally throughout the State with the exception of perimeter areas surrounding the "Thumb" and the western half of the Northern Peninsula; available locally in the excepted areas. Basic data on ground water adequate for a few areas; accelerated ground-water, surface-water, and quality-of-water studies needed.

Area of subject	Current situation	Deficiencies in information	Corrective measures and further development
Water supply	Public-supply and domestic use about 700 million gallons per day, about 200 million gallons per day ground water and 500 million gallons per day surface water (Detroit, 375 million gallons per day). Industrial use estimated at about 2 billion gallons per day, mostly surface water. Irrigation use about 26,000 acre-feet for 52,000 acres in 1949; increasing rapidly. Mostly surface water so far but ground-water use increasing because of relative availability and confused legal status of surface-water rights.	Quantitative data on stream flow and ground-water resources.	Establish a workable water-rights system for proper allocation of water and protection of all water rights.
Drainage	About 14,000 square miles drained, some inefficiently or overdrained. About 211 million gallons per day pumped from iron mines in Iron River district alone. Direct costs of drainage range from 20 to 30 cents per ton of ore produced; indirect costs perhaps 5 to 10 times as great.	Establishment of relation between drainage, flood control, ground-water levels, and lake levels. Economic studies of drainage of agricultural land and mines, including adequate program of research on design of agricultural drains.	State legislation patterned after Ohio's Water Conservancy District laws to provide for the handling of major drainage-basin improvements.
Flood control	Flood problems in lower stretches of Kawkawlin, Clinton, Rouge, Huron, and Raisin Rivers and in parts of Kalamazoo, Grand, Au Gres, St. Joseph, and Saginaw Basins and on Red Run.	Basic data on stream flow, precipitation, and siltation. Topographic mapping only one-third completed in State.	Enactment of Conservancy District legislation drafted to coordinate the study and mutual solution of all water problems to the benefit of all interests.
Lake-level stabilization	Conflicting demands for recreation, irrigation, and drainage uses.	Comprehensive collection of pertinent hydrologic data and comprehensive interpretive studies on inland lakes and small drainage basins.	Revision of State law, giving the State greater responsibility in stabilizing lakes and coordinating lake-level control with other water-resources problems.

Area of subject	Current situation	Deficiencies in information	Corrective measures and further development
Pollution of streams	Serious problems in St. Joseph, Kalamazoo, Grand, Saginaw, Black, Clinton, Rouge, Raisin, and Menominee Rivers, and others.	Comprehensive collection of pertinent data and interpretive studies of quality-of-water fluctuation from operation of natural causes.	Pollution abatement by cooperative means or court order.
Pollution of ground water	Local pollution of ground water by use of wells and pits for sewage and industrial-waste disposal. Widespread contamination of water in glacial drift in Saginaw Bay region by highly mineralized water leaking upward through abandoned coal-exploration holes and salt wells.	Comprehensive and continuing program of quality-of-water sampling. Intensive surveys of geology and hydrology in affected areas.	Large ground-water developments in Saginaw Bay area now limited to induced-infiltration supplies near streams. Contamination by oil wells controlled by adequate statutes since 1929. Similar control needed for abandoned water wells.
Battle Creek area	Ground-water withdrawal about 6 million gallons per day for public supply and 10 million gallons per day for industry. Aquifer connected with surface streams.	Maintain continuing program of data collection and study of local developments.	Pollution- and flood-control measures should recognize interconnection of surface and ground water to avoid depletion or contamination of ground water.
Kalamazoo area	Large ground-water developments for public supply and especially paper mills depend in part on recharge from Kalamazoo River, which is impeded by deposition of waste on river bottom.	Relation of lake levels to regional ground-water withdrawals to assist stabilization.	Pollution-control measures that will prevent sealing of river bottom. Control of base flow of river needed to assure recharge and also to stabilize ground-water levels.
Flint area	Public supply from Flint River; use about 25 million gallons per day. Low flow of river inadequate and conservation measures ordered several times in past. Future growth of city depends on solution of water problem.	Comprehensive information on regional hydrology to permit determination of safe yield from available sources.	Possible sources of increased supply are a reservoir on Flint River, pipe line to Lake Huron, and ground water. Studies needed to determine most economical source.
Pontiac-Oakland area	Heavy and increasing use of ground water for public and industrial supply. Decline of water levels in Pontiac. Surface supply from Clinton River developed for Pontiac 30 years ago but abandoned because of inadequate treatment facilities.	As above.	Lake-level stabilization needed: Possibilities of recharging ground-water aquifer with Clinton River water should be investigated.
Lansing area	About 20 million gallons per day withdrawn from sandstones for public and industrial use, water levels have declined.	As above.	Wider spacing of wells if potential legal problems can be worked out. Investigate possibility of induced-infiltration supply from gravels along Grand and Red Cedar Rivers, with artificial recharge of sandstones through present wells during periods of peak river flow, to provide water for periods of low flow when induced-infiltration supply might be inadequate.

Minnesota

Large available supply of ground water and few serious problems. Ground water available in glacial drift over most of State, (but good aquifers scarce in extreme western part) and in Paleozoic bedrock in southeast. Reconnaissance ground-water studies made for whole State but data lacking on current uses and local problems; detailed studies made in only three areas, only one covering a whole county. Some stream pollution from municipal, mining, and industrial waste; drainage and flood-control problems.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Twin Cities area	Public and some industrial supplies from Mississippi River. Off-river industries and suburban communities pump water from deep wells. Considerable decline in water levels in heavily pumped areas, but thought to be approaching stability in Minneapolis at present withdrawal. Contamination of deep aquifers by polluted or mineralized water from shallower beds through which wells pass.	Detailed study to obtain reliable estimate of dependable yield under given conditions of withdrawal.	Effective legal control by local or State agency to limit pumping to safe amount and require sealing or repair of wells contaminating aquifers.
Iron Range	Area bounded by Mississippi and South Kawishi Rivers; lies on divide and streams within area are small. Ground water scanty except in iron-ore bodies, water drained from which is used for such cities as Virginia and Hibbing. Concentration of low-grade ore will require large amounts of water for processing and increased domestic use.	Comprehensive water-resources study to determine most economical sources of water, including wells, mines (research needed on drainage design), and streams.	Formation of a conservancy district is a possibility. Water available from Mississippi amd South Kawishi Rivers if sources within area are shown by careful study to be inadequate.
Flood control	All large river basins in the State are subject to flooding from abnormal conditions of spring runoff. Most small basins are subject to flooding from heavy concentrations of rainfall due to local storms.		Projects in operation on Red River of the North and Minnesota Rivers; being considered for Roseau, Whitewater, and Root Rivers and others.
Drainage and lake-outlet dams	About 10 percent of total area is swamp; much of soil very rich when drained. Conflict among drainage and recreation and conservation interests.	Detailed studies of relation of drainage and cultivation to runoff and lake levels.	Integration of effect of drainage on lake-levels to serve all interests.
Stream pollution	Problems widespread; most critical in droughts of 1929-39 and would be repeated in another drought. Present critical areas include Minnesota River from Mankato to mouth, Crow River below Watertown, Zumbro River at Rochester,		Control measures based on adequate study to determine most economical methods.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Stream pollution (Continued)	Blue Earth River and tributaries at Fairmount and Blue Earth River at Winnebago, Le Sueur River at Waseca, Straight River at Owatonna, and Cannon River at Faribault. Streams in iron ranges affected by mine tailings and waste dumps.		

Mississippi

Well-watered State with abundant supplies but some serious water problems, which include floods, erosion, pollution, and local overdevelopment of ground water. Most rain in winter when water needs are smallest. Most of State in Coastal Plain and ground-water supplies abundant in most areas and used for great majority of domestic, municipal, and industrial uses. Whole State covered by reconnaissance ground-water studies and about half by more detailed studies. Annual runoff about 20 inches, but stream-flow data needed particularly for small basins where most problems occur. Quality-of-water data meager.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Floods	Damage mostly to agricultural lands, chiefly in Yazoo River flood plain. Problems on Upper Tallahatchie River at New Albany, Pearl River and Town creek at Jackson, Tombigbee River and Luxapalila Creek at Columbus, Sowashee Creek at Meridian, Leaf River at Hattiesburg, Mississippi River in southwestern part of State, and locally on most of other streams.	Studies of flood flow in wide, shallow valleys, particularly in small basins, with respect to control measures and highway, bridge, and railroad design.	Flood-control reservoirs on four largest tributaries of Yazoo under construction by Army Engineers; will largely solve problem in Delta. Similar measures needed for the other areas.
Erosion	Hundreds of thousands of acres ruined, much permanently.	Studies of economical soil-conservation and silt-control measures; of flood flows and silt transportation in small streams.	Erosion control based on adequate studies.
Pollution	Problems not as severe as in highly industrialized States; principal ones at Jackson, Meridian, Laurel, and near Gulfport.	Data on flow and purifying capacity of streams receiving sewage. Studies of ground-water contamination.	Sewage-treatment plants designed economically on basis of good data.
Ground-water levels	Some declines have occurred in large parts of State, in part by waste of water from flowing wells. No regional depletion but some local overdevelopment.	Basic and detailed studies of yield of aquifers.	Reduction of waste from flowing wells; development of ground water based on sound information.
Salt-water encroachment into aquifers	Encroachment occurred locally during war; likely to occur again as development of coast by industries and resorts increases.	Dependable yield of aquifers near coast.	Location of developments and regulation of withdrawal to prevent encroachment.

Missouri

Ample over-all water supply. Few problems, chief ones being floods and drainage. Some local pollution. Moderate to large ground-water supplies available in southern part of State, around "Ozark uplift" and in Coastal Plain in southeast; in northern part of State abundant supplies available only along present major streams or in buried preglacial valleys. Two-thirds of public-supply systems use ground water and larger ones use surface water. Total use of ground water estimated at 150-200 million gallons per day. Spring discharge, mainly in Ozarks, about 2.1 billion gallons per day, largely unused. No estimate of surface-water use available. Quality-of-water and silt data needed.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ground-water use and problems	Principal areas of heavy use are Columbia, Jefferson City, Springfield, Joplin-Carthage district, Neosho, and Sedalia. Water-level declines in deep-well areas, but local.	Detailed studies in areas of heavy use to determine yield under various conditions of withdrawal.	Supplies available outside areas of heavy pumping, or in some areas from other aquifers.
Joplin-Carthage district and rest of southwestern Missouri	Good water from deep aquifer but recharge and transmission rates rather low.	Regional study of principal aquifer and other possible sources.	Integrated development of aquifer in Missouri, Kansas, and Oklahoma; difficult because of uncertainties as to concept of "safe yield" of this type of aquifer. Shallower water is harder but may be useful for some purposes; creates mine-drainage problems.
St. Louis area	Ground water of good quality limited; only small area of permeable Mississippi River alluvium on St. Louis side. Deep wells yield little water or poor water; some problems of contamination of shallow water through defective or abandoned deep wells.		Repair or sealing of leaky deep wells.
Ozark area	Some ground-water pollution in areas of limestone sinkholes.		Chlorination or other sterilization; readily practiced on larger supplies but difficult for domestic users.
Sedimentation and stream pollution	Practically all streams carry much silt in floods; Missouri River, and its tributaries above Osage, carry silt most of time. Chemical quality generally good. Present or potential pollution at St. Louis and Kansas City and several minor areas.		Silt- and pollution-control measures based on adequate data, not now available.
Flood and drainage problems	Flooding of agricultural lands in practically all streams, principally on Missouri, Grand, and Mississippi Rivers and in Coastal Plain or "delta" in southeast. Also some flooding in lower Meramec Basin (St. Louis) and at St. Joseph, Kansas City, and other cities.	Data on flow of small streams is lacking for design of many flood-control projects.	Extensive flood-control structures have been built or are under construction. Future projects could be designed more economically if based on more adequate data.

Montana

Water situation variable. Alternating floods and scarcity in many areas. Extensive irrigated areas waterlogged; detailed ground-water investigations required preliminary to drainage. Ground water supplies 80,000 people in 78 communities and practically all of rural population. Some large ground-water reservoirs in State, capable of development for irrigation, municipal, or industrial uses, in some areas with beneficial effect on waterlogging. Ground-water data almost lacking; only recent studies being made as part of Missouri Basin program. General data on surface water collected but inadequate for detailed appraisal. Quality and sediment data meager.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Northeastern area	Local shortages of ground water for some of principal towns. Ground water largely of poor quality, even in productive aquifers in Missouri River flood plain and buried valleys under Medicine Lake and Culbertson-Bainville area. Surface supplies inadequate except along Missouri Valley.	Extent to which irrigation might affect quality of water in principal aquifers. More adequate stream-flow records for design of reservoirs. General ground-water studies made along Missouri River and in eastern Sheridan and Roosevelt Counties to evaluate ground-water supply and possibility of waterlogging from future irrigation.	Storage reservoirs and canals to provide irrigation water on tributary streams.
North-central area	Ground water generally of poor quality in western part of area, except in alluvial deposits whose occurrence is poorly known. Local depletion and encroachment of poor water at Havre, now shifting to Milk River for public supply. Potential serious problem of waterlogging in proposed Lower Marias irrigation project. Extensive waterlogging along Milk River and locally on Teton River, Blackfeet Indian Reservation, and Valier projects. Shortage of surface water for irrigation in dry season.	General ground-water studies. Only Lower Marias area studied to date. Stream-flow and quality data inadequate, especially on tributary streams.	Drainage of waterlogged lands, based on more adequate ground-water studies. Storage reservoirs for increased irrigation supplies. Coordinated irrigation development to achieve maximum utilization of water and prevent waterlogging.
Western area	Relatively abundant surface water and limited irrigable area. Drainage needed in Missoula Valley, Mission Valley, Flathead Indian Reservation, Little Bitterroot Valley, and between Kalispell and Flathead Lake.	Ground-water data inadequate. More stream-flow records needed for design of irrigation, flood-control, drainage, and power developments.	Area has considerable promise for additional development, if adequate studies are made.

Area of subject	Current situation	Deficiencies in information	Corrective measures and further development
Upper Missouri River area	Large undeveloped ground-water reservoirs present in Helena and Townsend Valleys. Drainage needed in parts of all principal irrigation projects, including Sun River, Helena Valley, Townsend Valley, and White Sulphur Springs area on Smith River. Surface-water supplies of tributary streams fully utilized up to limits of present storage.	Ground-water studies made recently in Helena Valley and parts of Townsend Valley. Data needed elsewhere.	Possibilities of ground-water development in Helena and Townsend Valleys to lower water table and provide irrigation supplies should be considered before large surface supplies are imported. Similar possibilities exist in other valleys and should be studied. Additional surface storage to permit fuller utilization for irrigation, especially in Sun and Smith River basins.
Central area	Large undeveloped ground-water reservoirs believed to exist in Judith River Basin and along Musselshell Valley. Irrigable land in Judith River Basin exceeds available surface supply, and storage is difficult because of flashy flow. Silt content of water high in lower Musselshell Basin. Drainage needed in Musselshell Valley.	Ground-water study needed in Judith River basin and Musselshell Valley. No recent studies in area. Records of stream flow needed to determine possibilities of further development.	Coordinated development of ground and surface water. Possibility of ground-water development in Musselshell Valley to relieve waterlogging and increase supply.
Southeastern area	Surface water generally deficient except on Yellowstone River and major tributaries. Drainage needed along Bighorn, Little Bighorn, and Yellowstone Rivers. Much of ground water is of poor quality. Silt content of most streams is a problem, especially along Powder River.	Detailed ground-water study to determine best methods of drainage (plans made for study of Buffalo Rapids project No. 1 near Glendive). Studies of availability of water for potential synthetic-fuel plants. Surface-water data lacking for small streams.	Coordinated irrigation development to relieve waterlogging and provide increased water for irrigation and other purposes, including synthetic-fuel plants.
South-central area	Drainage needed in some irrigated districts. Inadequate water for irrigation north of Yellowstone River and on Pryor Creek south of river.	Practically no data on ground water; studies needed to determine possibilities of development. Data on flow of small streams, especially tributaries of Shields and Yellowstone Rivers, needed for design of flood-storage reservoirs.	Increased surface-water storage north of Yellowstone.
Southwestern area	Large undeveloped ground-water reservoirs present in all principal valleys. Shortage of surface water for irrigation of higher lands. Large areas waterlogged in lower parts of Gallatin, Beaverhead, Jefferson, and Madison Valleys.	No recent ground-water studies. Needed in all irrigated areas, especially Gallatin, Beaverhead, Jefferson, and Madison Valleys.	Coordinated development of ground water in Gallatin Valley and other areas, to relieve waterlogging and provide water for lands not now irrigated. Some increase by surface storage possible; data reasonably adequate.

Nebraska

Water supply generally adequate and few serious problems so far. State contributions about 4.8 of 6 million acre-feet of water that flows out of it each year. Base flow of streams draining north-central area (Niobrara, Loup, and North Platte Rivers) unusually large and stable because of large ground-water recharge and storage in sand hills and underlying aquifers. Ground water widely available; scarce only in uplands of eastern quarter of State and extreme northeast and northwest. About 1,000,000 acres irrigated, 700,000 by gravity ditch and 300,000 from wells. Ground water and surface water closely related. General data more adequate than in many other States because of long-continued cooperative studies; however, detailed information, including quality and sediment data, badly needed for design of specific projects, to prevent expensive overdesign or disastrous underdesign. Presently authorized construction will cost more than a billion dollars and will have to be based on records of only 4 years for sedimentation and quality of water, and with few exceptions records of less than 20 years for surface and ground water, insufficient for most economical design. Cost of overdesign necessary for safety will be many times that of studies that should have but have not been made.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Niobrara River basin	Local minor problems of dry-season shortage and floods. Possible minor shortages in time of drought when development increases to contemplated maximum; also potential problem of waterlogging from increased irrigation.	Stream-flow data greatly inadequate for design of irrigation and power projects. Hydrologic studies needed for prediction of effects of development, which will change natural conditions.	Greatly increased development possible for irrigation (100,000-200,000 acres additional proposed for irrigation), and for hydroelectric power because of large base flow and availability of dam sites. Relatively large potential pumpage of ground water for irrigation; should be integrated with surface-water development.
North Platte River basin	Surface water almost fully utilized for irrigation. One of the most completely developed streams in country; flow largely stabilized. Surface water and ground water intimately related. Even with full utilization of available supply there is not sufficient water for all irrigable land.	Studies of complex relationship between ground water and surface water. Studies of water use and water loss to determine how much salvage can be accomplished, and the ultimate development that can be made. Quality of irrigation-return water especially important.	Increase of irrigation with ground water is possible to extent that it will relieve waterlogging and salvage natural waste by evapo-transpiration.
South Platte River basin	Flow of river allocated by interstate compact. Except for flood flows not controlled at present, water entering from Colorado is fully utilized. Ground-water development increasing and will interfere with surface flow.	Effect of present and future ground-water pumping on river flow; extent to which salvage of natural waste will be possible.	Integrated development to reduce waterlogging and natural waste by evapo-transpiration and achieve maximum utilization of water with minimum effect on quality of water leaving basin.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Lower Platte River basin	A major basin requiring integrated development of the intimately related surface water and ground water. Over-all supply appears to be adequate, but there are problems of interference with surface-water rights caused by increasing ground-water pumpage not now controlled by law; of loss of water from basin by underground flow to Republican River from lands south of Platte River irrigated by Platte River water, also creating a legal problem; of local declines of ground-water levels as in Grand Island-Kearney area, with more likely to occur as ground-water development increases; of drainage, also likely to increase; and of flash floods on tributaries.	Comprehensive hydrologic studies to guide design of projects to avoid local shortage or waterlogging (under way, in part). Data on distribution and storage capacity of ground-water reservoirs and their use for regulating and transmitting water in operation of projects. Studies of relationship of ground water and surface water and how operation of projects will be affected by this relationship. Quality of irrigation-return water especially important; also effects of channel aggradation and degradation.	Proposed to provide supplemental water for 418,000 acres now irrigated and provide water for 1,270,000 acres of new land; legal control by State over water of basin as a whole needed, which might be a stumbling block for whole project. Substantial progress being made in development as a whole.
Loup River sub-basin	Runoff, stabilized by ground-water storage in sand-hills region, is more than 1,500,000 acre-feet per year, more than adequate for expansion of irrigated acreage from present 39,000 to 350,000. However, prior rights to flow for power generation complicate development. Some drainage problems, more will develop. Floods in lower basin.	As above.	Integrated development for power, irrigation, and flood control. Ground-water development as necessary to control waterlogging and circulate water for reuse.
Elkhorn River sub-basin	Serious floods in lower basin, though flow in upper reaches is stabilized by sand-hills storage. Little irrigation development so far.	As above.	As above.
Kansas River basin - Republican River sub-basin	Ground-water reservoirs less important than in Platte Basin, base flow less, and floods and droughts severe.	Comprehensive hydrologic studies to predict effects of irrigation and determine potentialities of ground-water pumpage as part of coordinated development. Some studies in progress. Effects of channel aggradation and degradation.	Surface-water storage to stabilize flows and reduce effects of flood and permit extension of irrigation. Development proceeding rapidly by Bureau of Reclamation and Corps of Engineers.
Kansas River basin-Blue River sub-basin	Relatively little development except for power; Big Blue River almost completely developed for power. Ground water reservoirs less important than in Platte basin. Floods severe.	Comprehensive hydrologic studies as above (in progress, in part).	Flood-control reservoirs would reduce flood damage but are opposed by owners of land that would be inundated. Considerable additional irrigation and some power development possible if adequately planned.

Nebraska -- Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Basins of minor tributaries of Missouri River	Little development of water resources so far. Irrigation need less than in drier western part of the State. Low ground-water storage and severe floods.	As above.	Flood control complicated by relation to flood flow in Missouri River and by potential sedimentation of proposed control reservoirs. Many projects being designed without adequate basic data and will have to be expensively overdesigned to be safe.

Nevada

One of the few arid States of the West where ground water is only slightly developed. Surface supply largely appropriated. Future development depends on salvage of flood flows still escaping to areas below points of diversion, there to be evaporated, and of ground water evaporated and transpired along streams and in the many closed basins. Of the more than 30 principal ground-water basins only Las Vegas Valley is fully and Pahrump Valley almost fully developed. Total use in 1949 about 2 million acre-feet, about 1.8 surface water and 0.2 ground water. Loss by evapo-transpiration about 1.5 million acre-feet, of which possibly 0.4 million could be salvaged. Basic data inadequate but cooperative studies are being carried on as rapidly as possible to assure full and safe development. Available estimates of ground-water potential in most cases are preliminary and have not been determined reliably by adequate studies.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Salmon Falls Creek basin (Snake River drainage)	About 8,000 acre-feet per year used in Nevada. Controversy between users in Nevada and Idaho over water rights.	Data on flow above points of diversion in Nevada.	Interstate agreement based on better data as to total contribution in Nevada.
Owyhee River basin (Snake River drainage)	About 70,000 acre-feet per year used in Nevada. Some flood problems.	Flow data for South Fork of Owyhee River.	Agreement with Idaho as to use of water. Possible salvage of some evapo-transpiration waste.
Great Basin - Humboldt River basin	About 288,000 acres irrigated, surface-water requirement about 404,000 acre-feet. Problems include flood control, drainage in Lovelock Valley, effect of future up-stream storage on quality of water below Rye Patch Reservoir, and salvage of evapo-transpiration losses in middle section of river.	Flow data and comprehensive study of ground-water condition for middle section of river if salvage of water is to be attempted.	Additional upstream storage would prevent wet-year waste of water to area below diversions. Drainage and lowering of water table to reduce evapo-transpiration would salvage some water.
Elko area, Elko County	Current ground-water use 1,500 acre-feet per year, future use 3,000 acre-feet by 1970. Occurrence of warm to hot water locally limits use. Local decline of water levels.	Occurrence and quality of warm water; studies of proper well spacing.	Safe yield several times present use if properly developed.
Crescent Valley, Eureka and Lander Counties	Current ground-water use 1,000 acre-feet per year.	Precipitation data, stream-flow records, use of water by phreatophytes and data on direct evaporation, quality of water, occurrence and character of aquifers, to determine perennial yield. Topographic maps.	Total of about 10,000 acre-feet per year of ground water available.
Reese River Valley, Lander County	Present ground-water use 1,000 acre-feet per year. Potential ground-water yield 25,000 to 35,000 acre-feet per year, partly at expense of flow of Humboldt River; legal problem. Wells have low yields.	As above. Study of best well-construction methods.	Integrated development to salvage waste and minimize interference with river.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Paradise Valley, Humboldt County	Current ground-water use 1,000 acre-feet per year.	As above.	Total ground water available, about 15,000 acre-feet per year.
Grass Valley, Pershing and Humboldt Counties	Present ground-water use 300 acre-feet per year. Potential 15,000, in part at expense of Humboldt River; legal problem.	As above.	As above.
Lovelock Valley, Pershing County	Current ground-water use 1,000 acre-feet per year. Highly mineralized water in southern part and much of northern part. Drainage needed.	As above.	Safe yield several times current use. Wells on northeast flank of valley will get better water.
Great Basin - Truckee River basin	Current surface-water use about 300,000 acre-feet per year, including diversion of 210,000 acre-feet to Newlands Project in Carson River basin and 10,000 acre-feet for public use in Reno-Sparks area - largest surface-water use for public supply. Insufficient storage to stabilize level of Lake Tahoe. Flood-control and drainage problems. Interstate legal problems.	Additional stream-flow records, evaporation data on Lake Tahoe for full year.	Upstream storage to stabilize level of Lake Tahoe and permit increased use. Possibility of salvaging about 50,000 acre-feet per year flowing into Pyramid Lake. Salvage of water by drainage in Truckee Meadows east of Reno and of evapo-transpiration losses.
Truckee Meadows - Reno Sparks area, Washoe County	Ground-water use about 4,000 acre-feet per year, perhaps 10,000 in future. Warm water occurs locally. Possible pollution by septic tanks.	As under Crescent Valley. Also occurrence of thermal water.	Total of considerably more than 10,000 acre-feet per year of ground water available. Sewage-disposal system needed.
Great Basin - Carson River basin	About 48,000 acres in Nevada above Lahontan Reservoir irrigated with about 129,000 acre-feet of surface water per year, and 50,000 acres in Newlands Project with 470,000 acre-feet, including 210,000 diverted from Truckee River. Part of water wasted. Some flood problems, and drainage problems on part of Newlands Project. Interstate problems.	Stream-flow data to determine magnitude of evapo-transpiration waste.	More upstream storage to prevent wet-season waste and excess irrigation, improved irrigation practices to prevent waste, salvage of natural evapo-transpiration waste. and salvage of water by drainage.
Carson Valley, Douglas County	Current ground-water use 5,000 acre-feet per year. High water table in many areas; drainage needed locally.	As under Crescent Valley.	Total of about 10,000 acre-feet of ground water per year available.
Great Basin - Walker River Basin	Average total flow of river about 300,000 acre-feet per year, used mainly for irrigating 110,000 acres in Nevada and California. Stream about fully controlled. Some flood and drainage problems.	Surface flow into Smith Valley as source of ground water; flow of Walker River into Walker Lake.	Power development possible. Salvage of water wasted by evapo-transpiration would permit increased irrigation.

Nevada -- Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Smith Valley, Lyon County	Ground-water use 2,000 acre-feet per year. About 5,000 acre-feet per year could be withdrawn, depending on interference with flow of Walker River. Problem of drainage.	As for Crescent Valley.	Salvage of water by pumping in areas of high water table, or by means of drainage ditches.
Mason Valley, Lyon County	Current ground-water use about 1,800 acre-feet per year. Possible future use 5,000 acre-feet, depending on interference with flow of Walker River. Excessively high water table in parts of the valley.	As above.	As above.
Great Basin - ground-water basins not draining to principal streams of Nevada.			
Quinn River Valley, Humboldt County	Current ground-water use about 800 acre-feet per year.	As above.	Total of about 15,000 acre-feet of ground water per year available.
Fish Lake Valley, Esmeralda County, Nevada, and Mono and Inyo Counties, California.	Current annual use of ground water about 5,000 acre-feet from springs and 3,000 from wells.	As above.	Total ground water available annually estimated at 15,000 acre-feet under present conditions and 30,000 under long-term average precipitation conditions. Proposed development of 100,000 acre-feet per year for irrigation probably will be limited to annual recharge by State under existing law.
Newark Valley, White Pine and Eureka Counties.	Current annual ground water use about 5,000 acre-feet from springs and 100 from wells.	As above, plus spring-flow data.	Total ground-water supply about 20,000 acre-feet per year.
Diamond Valley, Eureka and Elko Counties	Current annual ground-water use 4,000 acre-feet from springs and 1,000 from wells.	As above, plus spring-flow data and data on deep ground water in relation to mining.	Total ground water available estimated at 15,000 to 20,000 acre-feet per year.
Dixie Valley, Churchill and Pershing Counties	Current annual ground-water use about 500 acre-feet. Water of poor quality in parts of valley.	As above plus occurrence of water of poor quality.	Total of 10,000 acre-feet per year of ground water available.
Buena Vista Valley, Pershing County	Current annual ground-water use about 100 acre-feet.	As above.	Total of about 5,000 acre-feet per year of ground water available.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Railroad Valley, Nye, White Pine, and Lincoln Counties	Current annual ground-water use 10,000 acre-feet from springs and 1,000 from wells.	As above, plus spring-flow data.	Total of about 25,000 acre-feet per year of ground water available.
Hot Creek Valley, Nye County	Current annual ground-water use about 1,000 acre-feet from springs and 100 from wells.	As above.	Total of about 5,000 acre-feet per year of ground water available.
Big Smoky Valley, Nye, Lander, and Esmeralda Counties	Current annual ground-water use about 1,000 acre-feet.	As above.	Total of about 20,000-30,000 acre-feet per year of ground water available.
Goshute-Antelope Valley, Elko County	Current annual ground-water use about 2,000 acre-feet from springs and 300 from wells. Water of unsuitable quality at some places.	As above, plus spring-flow data, occurrence of water of poor quality.	Total of about 2,500 acre-feet per year of ground water available from springs and 2,500 from wells. Large emergency withdrawals from storage possible, as during last war (true for many basins).
Clover Valley, Elko County	Current annual ground-water use about 3,000 acre-feet from springs and 100 from wells.	As above, plus spring-flow data.	Total of about 5,000 acre-feet per year of ground water available from springs and 10,000 from wells.
Ruby Valley, Elko and White Pine Counties	Current annual ground-water use about 5,000 acre-feet from springs and 100 from wells.	As above, plus additional spring-flow records and special attention to occurrence of poor-quality water.	Total of about 20,000 acre-feet per year of ground water available north of Franklin Lake.
Snake Valley, White Pine County, Nevada, and Utah (Nevada part)	Several thousand acre-feet from springs probably used annually for irrigation, plus about 1,000 from wells.	As above, plus spring-flow data.	Total of about 10,000 acre-feet per year available from wells.
Spring Valley, White Pine County	Current annual ground-water use about 5,000 acre-feet from springs and 1,000 from wells.	As above, plus spring-flow data.	Total of about 25,000 acre-feet per year of ground water available.
Steptoe Valley, White Pine and Elko Counties	Current annual ground-water use about 5,000 acre-feet from springs and 1,000 from wells.	As above, plus spring-flow data.	Total of about 45,000 acre-feet per year of ground water available.
Butte Valley, White Pine County	Current annual ground-water use 100 acre-feet from wells.	As above.	Total of about 5,000 acre-feet per year of ground water available.
Long Valley, White Pine County	Current annual ground-water use 50 acre-feet from wells.	As above.	Total of about 2,000 acre-feet per year of ground water available.
Ash Meadows, Nye County	Current annual ground-water use about 500 acre-feet from springs. High water table and lack of land suitable for irrigation.	As above, plus spring-flow data.	Total of about 10,000 acre-feet per year of ground water available, some possibly for export.

Nevada -- Continued

Area or subject	Current situation	Deficiencies in	Corrective measures and further development
Pahrump Valley, Clark and Nye Counties	Current annual ground-water use 20,000 acre-feet from wells and springs.	As above, plus spring-flow data.	Total of about 23,000 acre-feet per year of ground water available. Withdrawals should be held to safe yield.
Colorado River basin Colorado River (main stem)	Present use of Colorado River water in Nevada less than 20,000 acre-feet per year, at Basic Magnesium Plant at Henderson.		Proposed future development along river and in Las Vegas Valley to increase total to 197,000 acre-feet per year.
Las Vegas Valley, Clark County	Current ground-water use about 35,000 acre-feet per year, equal to estimated annual recharge. Local overdraft at Las Vegas. Water of poor quality in southern part of area, but not known to be encroaching.		Potential water demand estimated 80,000 acre-feet per year by 1970. Only apparent source of increased amount is Colorado River. Water district formed and negotiations under way with Colorado River Commission.
White River Valley, White Pine, Nye, and Lincoln Counties	Current ground-water use about 20,000 acre-feet per year from springs and 1,000 from wells.	As for Crescent Valley, plus data on occurrence of springs and on spring flow.	Total ground water available annually, about 40,000 acre-feet from springs and 19,000 from wells.
Meadow Valley Wash above Caliente, Lincoln County	Current annual ground-water use about 3,000 acre-feet. Water locally of poor quality in area of irrigation pumping and near Caliente.	As above, with special attention to occurrence of water of poor quality.	Total ground water available annually, about 6,000 acre-feet. Restriction of pumping in some areas to prevent encroachment of water of poor quality.
Pahranagat Valley, Lincoln County	Current annual ground-water use about 15,000 acre-feet from springs and 1,000 from wells. Waterlogging from spring flow in excess of use.	As above, plus comprehensive study of springs.	Total spring discharge about 25,000 acre-feet per year. Possible pumping from wells to dispose of surplus water recharged from spring flow and provide for additional irrigation.
Virgin River drainage	Current annual use of river water about 10,000 acre-feet. Quality poor, especially at low flow, and usable only by salt-tolerant crops. Silt content high during floods.	Quality-of-water data.	
Muddy River Drainage.	Current annual use of river water about 20,000 acre-feet and of ground water about 400 acre-feet.	Lack of long-term streamflow records.	Proposed additional use about 15,000 acre-feet annually, in part by pumping from Lake Mead. Flood control and storage for irrigation-season requirements needed.

New Hampshire

Ample water of good quality available, and few water-supply problems. Of total population of 525,000 to 550,000, about 290,000 are served with 32 million gallons per day of surface water and 110,000 with 10.4 million gallons per day of ground water from public supplies; remainder use largely ground water in rural areas. No great concentrations of industry and no serious shortages of supply.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Water power	Total developed power 328,700 kilowatts in 1948. Principal storage 30 billion cubic feet. Coordination with recreational use needed.		Estimates of feasible undeveloped power range from 121,000 to 422,700 kilowatts; feasible new storage 19 billion cubic feet. Conservation reservoirs used for power give some flood control and stabilization of lake levels for recreational uses.
Irrigation	Minor so far, but may increase in next few years.		State studying possible irrigation laws to prevent problems from arising.
Pollution	Not serious from water-supply standpoint; affects chiefly recreational activities.		Coordination of pollution-control measures and industrial needs (done by State).
Floods	Floods of 1927, 1936, and 1938 flooded 34,000 acres and caused damage of $31,300,000.		Considerable control afforded by power reservoirs and by flood-control reservoirs of Army Engineers.
Ground-water supplies	No serious problems; some failure of private wells during droughts.	Basic data largely lacking except for some on public supplies. Water-level data needed to guide future development.	Considerable additional data needed. Many productive glacial-gravel aquifers present but location and potential yield largely unknown. Bedrock yields small supplies.

New Jersey

Generally ample supplies but serious shortages or other problems in some areas. Flood control needed on certain streams, and projects proposed or under way. Pollution of some streams serious. Supplemental irrigation growing rapidly and will lead to some problems.

Area or subject	Current situation	Deficiencies in information	Corrective measures in further development
Northern metropolitan district	Thirty-three public-supply systems have total dependable yield of about 370 million gallons per day, 85 percent surface water and 15 percent ground water. About 525 million gallons per day needed by 1975 and 600 million gallons per day by 2000. Ground water developed rather fully as in Middlesex County.	More detailed studies of ground water to evaluate potential supply and relation to surface water; surface-water studies to permit most economical design.	About 25 million gallons per day can be developed from Ramapo River; and another 20 million gallons per day from Rockaway River for Jersey City. Tributaries of Raritan and Delaware Rivers could bring total to about 600 million gallons per day, including water that may be made available from main stem of Delaware River. Perhaps about 25 million gallons per day of additional ground water could be developed.
Southern metropolitan area	Area about 20 miles wide parallel to Delaware River from Princeton to Salem County line. Total municipal and industrial use about 125 million gallons per day, substantially over half ground water. Additional large quantities of surface water are used for cooling. Need 200 million gallons by the year 2000. Ground water heavily developed in Camden area; some interference between Camden and Philadelphia.	As above.	Additional water available from Delaware River for Trenton. Use downstream limited by pollution and salt water. Much ground water available in Coastal Plain outside Camden and adjacent area, particularly Burlington County and part of Mercer County; safe yield uncertain but studies under way. Delaware River may be substantial source of recharge at Camden; if so, draft could be increased, but pollution may make river undesirable as source of recharge.
Atlantic Coastal region	Area from Raritan to Cape May, mainly a resort area but industry increasing. Total use of water about 60 million gallons per day, about 3/4 ground water. Need may be 100 million gallons per day by 2000. Salt-water encroachment in several places, notably the coastal part of Middlesex County and the area from Beach Haven to Cape May, which includes Atlantic City.	Safe yield of coastal ground-water supplies; additional gaging stations on streams.	Ample water available if developed properly to prevent salt-water encroachment.

Area or subject	Current situation	Deficiencies in information	Corrective measures in further development
Southern interior district	Present use about 25 million gallons per day.	Detailed ground-water studies; additional gaging stations on streams.	Estimated safe yield of ground water and surface water together about 500 million gallons per day. Dam sites lacking; necessary to use unregulated flow of surface streams. Use of ground water in periods of low stream flow and of surface water in wet weather would keep ground-water reservoirs recharged and permit maximum development.
Flood control	Problem on Passaic River and other streams.	Additional stream-flow data, and analysis of data to predict flood frequencies.	Proposed Army Engineers project would provide multiple-purpose reservoirs above Two Bridges, plus channel improvement. Conservation pool would be available for limited recreation use and for water supply, power, increased low flow, and pollution abatement. Dry detention reservoir above would provide flood control. Channel improvement completed on four other streams and work planned on others, including some detention reservoirs.
Supplemental irrigation	Practice growing rapidly. From 4 to 12 inches of water applied from most convenient source, including some from public supplies. Perhaps 30 to 100 million gallons per day now used; total will increase greatly. Water largely evaporated and transpired; not available for reuse.	Safe yield of ground-water reservoirs in cultivated areas; data on flow of small streams usable for irrigation.	Regulatory authority over surface waters lacking. State has authority to control ground-water withdrawals, and should be able to do so on the basis of good data to prevent over-development but avoid discouraging full development.

New Mexico

Largely semi-arid State with relatively small over-all water supply. Drained by Rio Grande and Pecos, Canadian, Gila, and San Juan (Colorado River tributary) Rivers. Rio Grande and Pecos fully developed; some available from Canadian and Gila; about 800,000 acre-feet per year from San Juan under Upper Colorado River Compact. Something more than 500,000 acre-feet of ground water used, chiefly for irrigation. Some additional supplies available by salvage of natural waste. Basic data needed on ground water, quality of water, silt problems, and flow of certain streams.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further developments
High Plains	Little surface runoff except in storms. Chief use of ground water in other than developed areas is for municipal, ranch, and oil-well-drilling supplies. High fluoride content in some of ground water. Ground-water recharge low; heavy developments deplete stored water. Situation similar in principle to that in southern High Plains of Texas.	Gaging of ephemeral arroyos for design of flood-detention reservoirs for recreation and other uses. Data on availability of ground water for towns and small irrigation districts.	Except for areas described below, development is light. Control of withdrawals necessary; probably possible under State law, but difficult because of uncertainty as to best use of an exhaustible resource. (See discussion of High Plains of Texas in text).
Lea County Irrigation District	Heavy development of ground water for irrigation started in 1948; 39,000 acre-feet pumped in that year. Water levels lowered 2 feet over 24 square miles in a year and will continue to fall.	Continuing records of pumpage and water levels to show rate of depletion of ground-water storage.	Administrative decision as to best way to control depletion of storage. Further extension of irrigation stopped by State. Optimum development difficult to determine because of uncertainty as to best use of an exhaustible resource.
Portales Valley	Intensive development of ground water for irrigation started in 1930; 44,000 acre-feet pumped in 1947. Water levels declined 20 feet or more in 11 square miles from 1942 to 1949 and will continue to fall.	As above.	As above, but development not yet curtailed by State.
House area	Intensive development of ground water for irrigation started in 1940; 4,000 acre-feet pumped in 1948. Water level declined 6 feet or more in 2.4 square miles, 1942-48, and will continue to fall.	As above.	As above.
Pecos Valley	Pecos River Compact provides that New Mexico will not deplete river below 1947 conditions.	About 16 new gaging stations needed for administration of compact and operation of existing and possible new projects. Study of sediment load of Pecos River.	Additional use of surface water possible only by reducing waste by phreatophytes, principally saltcedar in Lake McMillan, and by importation of water.
Roswell Basin — artesian water	Intensive use of ground water for irrigation started in 1915; 211,000 acre-feet withdrawn in 1948. Water levels declined average of 11.8 feet from 1941 to 1949.	Detailed data on pumpage and water levels to guide control by State. Effect on ground water of proposed flood-control works. Study of possible	Irrigation with artesian water probably will stabilize at about present level. Possibility of metering wells to prevent withdrawals from some in excess of water rights.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further developments
		salt-water encroachment from northeast part of basin, including additional quality-of-water data.	Further extension stopped by State. Adjustment of New Mexico-Texas interests as affected by flood control.
Roswell Basin — shallow ground water	Intensive use of ground water for irrigation started in 1936; 121,000 acre-feet pumped in 1948. Water levels declined 20 feet or more in 65 square miles, 1942-48, and will continue to lower. Further depletion of flow of Pecos River will occur as a result. Some land may be forced out of cultivation owing to decline of water level.	More data on effect of pumping on river flow. Study of possible salvage by eliminating saltcedars. Continuing data to guide regulation by State. Effect of withdrawal on artesian basin; quality data needed for this purpose.	Elimination of artificial and natural waste so far as possible. Development stopped by State to prevent an increase in rate of depletion.
Roswell Basin — Salt Creek artesian area	Intensive development of ground water for irrigation started in 1948. Pumpage not known. Development might reduce salt-water encroachment into main basin but more likely will accelerate it.	Effect of development on main Roswell Basin and on flow of Pecos River. Quality data badly needed.	Extension of present irrigation stopped by State to prevent overdevelopment, injury to main basin, and interference with prior rights there.
Carlsbad area	Intensive use of ground water for irrigation started in 1948 mainly to supplement water from Pecos River. Pumpage not known. Water level lowered 6 feet or more in 4 square miles, 1948-49. Pumping will reduce flow of Pecos River.	Possibility of interception and disposal of salt spring water discharging about 325 tons of salt per day into Pecos at Malaga Bend. Quality-of-water data to assist in determining source and movement of fresh and salt water in area.	Regulation by State to prevent overdevelopment and to satisfy terms of Pecos River Compact.
Rio Grande Valley	Maximum development reached with present water supply. New Mexico has been unable for past 7 years to deliver to Texas full amount required under Rio Grande Compact, owing largely to increased waste by saltcedars above San Marcial. River carries much silt, contributed mostly by Chama, Jemez, Puerco, and Salado Rivers.	Possibility of reducing waste by saltcedars (under study by Corps of Engineers and Bureau of Reclamation).	Flood-control and silt-storage reservoirs authorized for Chama and Jemez. Wagonwheel Gap dam on Rio Grande would further stabilize flow and reduce silt movement. Possibility of diversion from San Juan Basin (Colorado River drainage) to increase supply for Rio Grande.
Elephant Butte Irrigation District	Use of ground water for supplemental irrigation started in 1948. Amount used so far comparatively small. Pumping will reduce flow of river.	Continuing detailed data on water levels and effect of pumping.	Use of ground-water storage by pumping will help provide water to those having wells when surface supply is low, to the detriment of those without wells. Regulation needed to adjust inequities between those having no wells and those who do and who also receive a full share of surface supply. Pumping may salvage small amounts now wasted by evapo-transpiration.

New Mexico -- Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Middle Rio Grande Conservancy District	Possible deterioration in quality of ground water pumped for Albuquerque public supply. Drainage problems acute because of rise of water table caused by surface-water irrigation and rise of river bed caused by silt deposition. Sediment load limits usefulness of surface water. Intensive municipal use of ground water started in 1940, current total use 15,000 acre-feet per year. Little lowering of water level. Pumping will reduce flow of Rio Grande, already inadequate.	Studies of changes in quality, methods of drainage, and sediment (latter under way). Possibility of salvaging evapotranspiration waste. Effect of development of ground water upon over-all supply. Legal relationship of ground and surface water. Need for 69 new gaging stations in middle Rio Grande for studying water-conservation possibilities and methods of rehabilitating present irrigation system.	Regulation to prevent over-use of water supply as a whole. Continued shortage of surface water is providing incentive for development of ground water for irrigation, which in turn may cause greater shortage of surface flow.
Valle Grande area	Tentatively proposed use of 3,000 acre-feet of ground water per year for Los Alamos would deplete by like amount the flow of water used by Indian pueblos along Jemez River. High fluoride in some water of Valle Grande area and high boron in hot spring water.	Study under way to determine seriousness of problem.	Adjustment, if needed, of interests of both Los Alamos and Indians, subject of recent negotiations. Proposed supply would not be developed for Los Alamos if adequate water could be found to the east.
Upper Rio Grande Valley in New Mexico	Chief use of ground water is for Los Alamos; entire demand for Los Alamos likely will be met by wells west of Rio Grande. Pumping will eventually reduce flow of river at Otowi, key gaging station for operation of Rio Grande Compact.	Detailed data on effect of pumping on river flow, lag in effect, and adequacy of supply.	To be determined after further study.
Bluewater area	Intensive use of ground water for irrigation started in 1945; 9,300 acre-feet used in 1948. Average water level lowered 8.2 feet, 1946-50. Pumping will affect flow of springs into Bluewater River.	Study of possible adverse effect of proposed flood-control measures on Indian water rights; effects of pumping on prior rights. Effects of pumping on quality of water.	Flood-control measures that will not affect water rights adversely; adjustment of water rights for effects of pumping.
Remainder of Rio Grande Valley	Use chiefly for ranches.	Quality-of-water and sediment data. Studies of ground-water occurrence to determine best areas for ranch wells and possibilities of local irrigation. Studies to determine whether flood-detention dams on arroyos will increase recharge and total water supply of valley.	

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Closed basins	No surface outflow, except from northwest part of Virden Valley (part of interstate Duncan-Virden Valley), drained into Arizona by Gila River.	Additional gaging stations to determine inflow of streams into the closed basins, as part of studies to determine ground-water recharge and possibility of increasing it by constructing dams on arroyos to catch flood waters now wasted to dry "playa" lakes.	
Gila River Basin in New Mexico (Virden Valley)	Irrigation from streams and wells.	Studies to determine safe yield.	Additional development appears possible. Should be coordinated with use in Arizona to produce maximum utilization and equitable distribution of water. Good reservoir sites at Hooker and Red Rock. Lands near Gila, Cliff, and Red Rock could be irrigated.
Crow Flats area (extends into Texas as Salt Flats area)	Basin of internal drainage in New Mexico and Texas. Successful irrigation from wells in Texas part has led to more than 1,000 homestead applications in New Mexico. Encroachment of salt water from lowest part of basin may be caused by pumping.	Studies to determine possibilities of development and effects of pumping.	Potential development likely to be small. Needed are regulation of excessive development in order to limit encroachment of salt water; coordination of development with Texas.
Tularosa Basin	Ground water mainly of poor quality. Water supply of Alamogordo and Holloman Air Force Base inadequate; supplementary supply of latter increasing in salt content. Recharge of basin small.	Studies to determine source of additional water for Alamogordo area; of occurrence of salt water and of possible fresh water for irrigation and other uses in all parts of basin. Availability of water for White Sands Proving Ground.	
Estancia Valley	Intensive use of ground water for irrigation started in 1948; 5,400 acre-feet withdrawn in that year. Water level declined 1 foot or more in 72 square miles, 1948-49. Water of poor quality in much of basin.	Studies of perennial yield; occurrence of salty water and movement under pumping conditions.	Regulation to prevent overdevelopment and salt-water encroachment.
San Augustin Plains	Present use mainly on ranches.	Studies to determine whether large quantities of water of good quality are available for irrigation or defense establishments.	Probably more water is available than is being used.

New Mexico — Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Mimbres Valley	Intensive use of ground water for irrigation started in 1923; 58,000 acre-feet used in 1948. Water level lowered 10 feet or more in 10 square miles, 1942-48. Recharge mainly from Mimbres River, reduced by full development in headwaters. As ground water is pumped mainly from storage, water levels will continue to lower. Some water high in fluoride.	Continuing records of pumpage and water levels needed to show effects of pumping and rate of depletion of storage.	Regulation in accordance with policy decision as to best way to utilize water where withdrawal exceeds recharge, as in developed areas of High Plains. Further development in main area stopped by State.
Animas and Playas Valleys	Intensive use of ground water for irrigation started in 1948; 7,000 acre-feet withdrawn in that year. Water level declined 3 feet or more in 4 square miles, 1948-49. Water rather high in sodium and may give trouble on heavy soils; high in fluoride in some places.	Determination of perennial yield.	Hold withdrawal to perennial yield, or make decision as to best rate of depletion of storage if recharge proves to be small.
Other closed basins in southwestern New Mexico	Use now chiefly on ranches.	Availability of water for municipalities and perhaps for irrigation. Possibility of increasing recharge by damming arroyos to catch flood flows.	Some development of ground water for irrigation may be possible.
San Juan Basin	New Mexico allotted about 800,000 acre-feet per year under Upper Colorado River Compact. Reported losses from San Juan River suggest substantial underflow from State or evapo-transpiration. Estimates probably in error.	Careful study of losses to determine effects on Upper Colorado River Compact.	Use of water to be determined after further study.
Navajo Reservation	Water needed for Indian schools and settlements. Water scarce and careful investigation needed to locate economical supplies.	Studies under way; should be continued to cover reservation.	
Canadian River basin	Irrigated areas on Cimarron, Rayado, Vermejo, and upper Canadian Rivers now deficient in water supply.	Seven additional gaging stations needed to determine amount and distribution of water in streams; quality of irrigation-return water from Tucumcari Project in relation to reuse.	Possibility of diversion from Red River (tributary of Rio Grande) when diversion is made from San Juan to Rio Grande, for use in Antelope Valley in Rayado River basin. Possibility of storing water on Ute Creek, tributary to Canadian.
Remainder of New Mexico	Water needed for municipalities, ranches, and defense establishments. Irrigation would be desirable also.	Studies to locate supplies.	Development of ground water for irrigation in local areas probably feasible. Control may be needed where flow of streams may be affected.

New York

Vast water-resources potential and large use. Less than 5 percent of watershed area developed so far. Much of remaining water used for power but most plants are "run of the river" rather than depending on storage, and interference between power and other uses is small. Water-supply problems acute in few places; chiefly economic or caused by delay in development, rather than hydrologic or engineering difficulties. Some flood problems, largely under control or in process of being controlled. Considerable stream pollution. Ground water abundant on Long Island and in present or buried preglacial valleys in Upstate New York; supplies from bedrock smaller but developments of 0.1 million gallons per day or more possible in much of western part and in scattered areas elsewhere. Overdevelopment in western Long Island; only local depletion elsewhere. State has 1 area using more than 1 billion gallons per day (New York City); 5 areas using 100 million gallons per day to 1 billion; 6 using 10-100 million gallons per day; and 47 using 1-10 million gallons per day(large power plants and pulp mills not included). Stream-flow data good on the whole; more data on small streams and analysis of all data needed for use in specific projects. Ground-water information good for Long Island and Upstate studies progressing. Quality-of-water data badly deficient.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
New York City	Supplies a little more than 8,000,000 people in the five counties of New York City plus large population in Westchester County and communities above Catskill and Croton Aqueducts (32 million gallons per day to these areas outside city in 1948). Demand rose to 1,200 million gallons per day by 1949, about 20 percent beyond dependable yield (315 million gallons per day from Croton, 10 from Bronx and Byran, 525 from Schoharie and Esopus, 20 surface water and 80 ground water from Long Island, and 5 ground water from Staten Island; will be increased by up to 100 (not dependable) from Rondout Creek into Catskill Aqueduct at Lackawack). Above-normal precipitation permitted overdraft in 1945-48, but drought of 1949 reduced supply. War and court actions have delayed additions to supply in last 15 years. Storage was 90 percent of capacity (122 percent of normal) at end of February 1949, and 100 percent by the end of April; was as low as 33 or 34 percent of capacity late in 1949 and at end of February 1950 was 47 percent of capacity (64 percent of normal).		Demand reduced by 200-300 million gallons per day by conservation measures. It is now proposed to divert 100 million gallons per day from Hudson River to Catskill Aqueduct by late summer 1950. Development of upper Delaware supply being rushed. Ground-water pumpage on Long Island being accelerated to permissible maximum of 100 million gallons per day(averaged 55 million gallons per day in 1949). Rondout supply of 100 and Neversink supply of 105 million gallons per day to be completed in 1953; East Branch Delaware supply of 335 million gallons per day in 1956. Total dependable yield will then be 1,495 million gallons per day; expected demand 1,350 in 1956. Additional developments needed for expected continued increases in demand after 1956. Continued conservation needed until reservoirs return to normal stages, and afterward until development catches up with demand.
Public supply in general	In 1948, 354 surface-water systems served 10,891,482 people in 637 communities, 479 ground-water systems 1,749,315 in 479 communities, and combination supplies 123,524 in 43 communities, for a total population of 12,764,321. Rural population (remainder	Data on present water demands and future needs. Local studies as needed to determine most economical sources.	Principal needs for increased supply at present are New York City and in northwestern part of State.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
	of total now estimated at 14,750,000) uses largely ground water.		
Northwestern area (Erie, Niagara, Orleans, Genesee, Monroe, and Wayne Counties and parts of Livington and Ontario Counties)	In area at east end of Lake Erie and south side of Lake Ontario most communities need to expand their water supply, as shown by effects of drought of 1949. In 1948, 1,457,635 people were served with 235,886,000 gallons per day of surface water, 4,243,000 of ground water, and 1,625,000 from combination supplies, and demand has increased since then.		Northwestern New York Water Authority District formed, as recommended in Hollinger Report of State Committee on Northwestern New York State Water Supply. Recommended to develop 121 million gallons per day of gravity surface water immediately, mostly at south edge of area. Possible later construction of pipe line from Lake Erie east about to Rochester, Buffalo, Rochester, and some other large cities may develop supplies individually rather than under an authority. Ground-water supplies not available in sizable quantities except possibly in buried valley in Genesee River basin.
Ground water in Upstate New York	Total ground-water use about 400 million gallons per day. Large supplies, 4-30 million gallons per day, developed only in "Southern Tier" of counties and in east. Principal areas are "Triple Cities" (Binghamton, Johnson City, and Endicott), 30 million gallons per day; Schenectady area, 25 million gallons per day; Jamestown, 5-6 million gallons per day; Corning, 5 million gallons per day; Elmira-Horseheads, 4 million gallons per day; Cortland, 4-5 million gallons per day; plus 1 to 4 million gallons per day at 15 to 20 other places. Local water-level declines in several places, notably Triple Cities and Jamestown, but no regional overdevelopment known. Drought of 1949 affected many shallow rural wells and also shallow public wells of Lathams Water District; no long-term declines. Quality limits ground-water development in some areas, especially in eastward-narrowing belt extending from Buffalo through Syracuse and Utica nearly to Albany.	Extension of present coverage by cooperative studies with State Water Power and Control Commission to cover the many areas of deficient ground-water and quality-of-water information. Records of only 10,000 of estimated 500,000 wells collected so far. Data needed include records of use of ground water, quality data, completion of geologic mapping, location of aquifers by geologic study, test drilling, and geophysical studies, and observation-well records in both pumped and unpumped areas.	Demands to increase, as in Triple Cities area, Schnectady, Cortland, possibly certain places in Westchester County, Beacon area, Lathams Water District near Albany, Rensselaer, Utica, Syracuse, and Rochester. Greatly increased development appears possible if based on good data. State considering extension of present legal authority over ground-water withdrawal on Long Island to whole State, to provide against overdevelopment.

New York -- Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Flood control	Principal problem on Susquehanna and Genesee Rivers and Onondaga Creek above Syracuse, also on Hudson, Mohawk, Hoosic, and Little Hoosic Rivers and Kinderhook Creek.		Susquehanna project by Army Engineers in cooperation with State involves 9 dams (4 completed), and 14 local improvements (12 completed); total cost $82,007,300. Other projects constructed or authorized total $126,701,720.
Pollution	Special Committee on Pollution Abatement lists 549 sources of stream pollution, 44 percent sewage, 19 percent milk-plant wastes, and 37 percent other. Hudson River from Troy to New York City, Niagara River, Mohawk River, and Onondaga Lake are among principal polluted surface-water bodies.	Analysis of existing and future stream-flow records to determine design of systems providing adequate dilution at low flow. Data on silt as a phase of pollution. Present stream-flow records very inadequate to determine classification of streams under new law.	Sewage-treatment plants serve 6,964,000 people; 4,694,000 more are in communities having sewer systems but no treatment. Under consideration are 118 new projects. Few data available on industrial-waste problems. Water Pollution Control Board formed under law recently passed.
Long Island	One of the most productive ground-water areas in country, formed largely of sandy glacial deposits underlain by Coastal Plain deposits including some sands. Limited surface runoff, largely reflecting drainage from ground-water reservoir. Average potential ground-water recharge estimated at half of precipitation or 1 million gallons per day per square mile, or 1,374 million gallons per day total. Minimum dry-year potential recharge estimated at 955 million gallons per day. Recharge reduced by about 90 million gallons per day by pavements, buildings, drainage into sewers, etc. Estimated safe pumpage, 1,284 million gallons per day in average year and 865 million gallons per day in driest year (requiring wells scattered over entire island and requiring return of part of water to ground all along shore to prevent salt-water encroachment). Withdrawal in 1949 was 270 million gallons per day including 55 by New York City; net pumpage reduced to 150 million gallons per day by recharge through artificial-recharge wells and basins, treatment plants, septic tanks and cesspools, etc. Overdevelopment and salt-water encroachment in Kings and Queens Counties, though less than formerly. However, accelerated pumping in Nassau County by New York City in present water shortage is being watched carefully to see that salt-water encroachment does not result. Local problems of pollution by organic or other wastes, such as problem of high nitrate in shallow aquifers	Continuing detailed studies to guide control by State; additional data wherever new problems arise, as increased pumping by New York City in Nassau County and increased irrigation developments in eastern part of island. Stream-flow data inadequate to guide pollution control and operation of fish-rearing ponds and shellfish industry.	Continued reduction of net pumpage in Kings and Queens Counties by reduced withdrawal and artificial recharge until it is within safe yield. Large additional developments possible in unpumped areas of Nassau County and especially Suffolk County where concentration of pumping is least. Supplemental irrigation from wells promising and increasing rapidly.

North Carolina

Large potential supply with proper development. Local shortages of surface water and overpumping of ground water are common, but problems are mainly economic and there is no regional overdevelopment. Stream pollution is most important surface-water problem, followed by flood control and drainage. Main ground-water problem is need for information on occurrence and availability of water of good quality, to permit most economical solution of problems of overpumping and increasing demand. Many additional records of flow of small streams needed, as these will be tapped increasingly for new supplies.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Coastal Plain	Area not industrialized heavily but development increasing, especially for paper mills and steam-power plants. Surface-water supplies large and of good chemical quality except near mouths of streams and for iron-bearing high-color waters in Dismal Swamp region. At least 50 million gallons per day of surface water used at paper mills, and steam-power plants have maximum demand of more than 450 million gallons per day. About 3,000 horsepower of hydro-power developed at small mills. About 25 million gallons per day of surface water used for 20 public systems. About 16 million gallons per day of ground water used for 90 public supplies; about 50 million gallons per day for industrial uses. During the war defense establishments used about 20 million gallons per day, all from ground water except Ft. Bragg, which uses surface water. Pollution common, especially in Neuse, Roanoke, and upper Cape Fear Rivers. Major flood problems in Roanoke, Cape Fear, and Neuse River basins. Ground water high in fluoride north of Greenville, high in iron in many parts of area, and salty in many coastal areas.	Occurrence of ground water of good quality; extent of salt-water encroachment, if any; safe yield of aquifers as a whole, but especially with regard to local developments and availability of fresh water near coast. Research on problem of iron in water.	Very large ground-water potential if adequate data are obtained. Control of floods in Neuse and Cape Fear Basins needed; will be effected to some extent on Roanoke River when Buggs Island Reservoir in Virginia is completed. Pollution-control measures would increase availability of surface water, limited by this and by salt water near coast.
Piedmont Plateau	Most heavily populated and industrialized region. Water of generally good chemical quality except for iron in ground water in places. More than 520,000 horsepower of hydro-power, and steam-power plants capable of using 900 million gallons per day of surface water. Amounts used for other industrial purposes unknown, but larger mills develop more than 20,000 horsepower of hydro-power with surface water. About 63 million gallons per day of surface water used for public supply in 64 communities; about 5 million gallons per day of ground water for 53 communities. Ground-water supplies in bedrock small to moderate; heavily pumped for towns and industries and locally overdrawn. Stream pollution acute in Dan River, Neuse River below Durham, Haw and Deep Rivers, headquarters of Rocky River, and Yadkin River from	Occurrence of ground water in bedrock, to help locate successful wells (considerable data already gathered). Flow of small streams and research on relation of ground-water levels to stream flow to assist in predicting low flow. Increasing need for temperature data on ground and surface water. Information on silt movement in streams and silt deposits in reservoirs.	Pollution control needed. Flood-control measures proposed for study in major problem areas. Erosion and silt control needed in areas of severe erosion. Wider spacing of wells in heavily pumped areas will solve most problems of local overdraft. Studies show moderate to large supplies available from thin alluvium along streams; almost untapped.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
	Wilkesboro to Winston-Salem. Flood problems on upper Yadkin River and on Cape Fear and Neuse Rivers. Local shortages of surface water and ground water common, especially at Raleigh and Winston-Salem. Soil erosion and sedimentation problems.		
Appalachian region	Use of water not heavy. Water of good quality. Five large plants use 110 million gallons per day of surface water. About 11.5 million gallons per day of surface water used for 36 public supplies, 900,000 gallons per day of ground water for 26 public supplies. Hydroelectric-power development more than 500,000 horsepower. Stream pollution serious on French Broad River from Rosman to State line, Tuckasegee River from Sylva to Fontana Reservoir, and Pigeon River from Canton to State line; also from mica-plant waste in North Toe River. Flood problem in French Broad River; less serious elsewhere. Drainage of some high plateau land needed for agriculture.	As above.	As above.

North Dakota

Water is limiting factor in development of almost all of State. Bulk of 15 to 22 inches of precipitation occurs in growing season and is consumed by evapo-transpiration, leaving little for ground-water recharge and stream flow; runoff an inch or less in almost all of State. Ground water used for over 70 percent of domestic, stock, industrial, railroad, and public supplies. Surface-water use mainly along Missouri and Red Rivers. Increased surface water to be made available under Missouri Basin program; irrigating will increase ground-water supplies in some areas but will lead to drainage and salinity problems; increasing farming, and industrialization resulting from increased hydro-power, will increase demand for ground water for domestic and industrial use. Ground water available in limited quantities in glacial deposits in northeastern two-thirds of State, in bedrock mainly in western half but some water from Dakota sandstone in eastern part. Few large supplies except along major streams. Water from Dakota sandstone generally of poor quality; that from glacial drift and from other bedrock aquifers also poor in many places.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
	Principal problems are lack of water of good quality to meet all municipal, industrial, and irrigation needs; and of water of any quality for sewage dilution. Infrequent but severe floods on all streams; for example, recent floods on Red River, which were most severe north of international boundary. Pollution in many streams. Drainage in Red River Valley, and lack of suitable reservoir sites; reservoirs would cover valuable land and would have high evaporation losses. Soil erosion and sediment in streams.	Expansion of ground-water studies under Missouri Basin program and in cooperation with State to provide adequate data for most economical solution of local problems. Quality data for this purpose and to guide irrigation development when large return flows become available. Increased stream-flow data and analysis, in relation to flood and low flows, movement of salty return water from irrigated lands, proposed flushing of salty water from Devils Lake basin into Sheyenne River and Red River. Sedimentation in relation to reservoir operation and life.	Adequate surface water along Missouri River; storage in reservoirs at Garrison, N. Dak., and Oahe, S. Dak., will provide irrigation water for northwestern and central parts of State. Diversion from Missouri to Sheyenne and then to Red River at Fargo will help eastern area. Ground water can be made available for most domestic needs, but not always at low cost or of good quality. Full coordination of Federal, State, county, and municipal activities needed to achieve maximum use of the limited water resources.

Ohio

Generally ample water supply but some problems of local overdevelopment, stream pollution, flood control, soil erosion, and sedimentation. Problems largely economic rather than hydrologic or engineering; solutions exist but cannot always be applied economically.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ground water	Ground-water use about 550 million gallons per day, 400 by industries and 150 for public supply, mostly from gravel-filled preglacial valleys. Much of water derived from streams by induced infiltration. Similar aquifers scattered over State but mostly in southern half. Limestones yield moderate supplies in western part and scattered sandstones in east. Ground-water pumpage of 1 million gallons per day or more in 33 areas. Mill Creek Valley fully developed as a whole; local overpumping in some other areas. Ground water scarce and of poor quality, except locally, in area adjacent to Lake Erie and eastern and southeastern areas.	Adequate general studies completed in only 7 counties and under way in 9 more; quantitative studies made in only a few areas such as Cincinnati, Dayton, and Canton; under way in a few others. General studies needed in rest of State and quantitative studies in all areas of heavy withdrawal. More adequate mapping of sandstones in eastern Ohio, where substantial ground-water supplies are otherwise limited to buried valleys.	Buried valleys, especially Ohio Valley where there are few large developments so far on Ohio side, have great potential for large supplies by induced infiltration. Water slightly more mineralized than river but bacterial and some industrial pollution largely filtered out. Effect of induced infiltration on flow of smaller streams must be considered.
Surface water	Problems similar to those in other heavily farmed and industrialized States in humid region; large supply but pollution, floods, and erosion and sedimentation widespread. Use of surface water not known but very large, much larger than ground-water use. Numerous cases of local shortage or overdevelopment; Youngstown area on Mahoning River is outstanding example, where river water is reused many times and heavily polluted and heated. Ohio River extensively polluted.	Stream-flow records reasonably adequate except for a dozen ungaged basins of 100-400 square miles, mostly adjacent to Ohio River. Analysis of data needed for correlation of flow with ground-water levels, flood prediction, relation of runoff to precipitation in cultivated and uncultivated areas, etc.	Economical development of additional supplies, in addition to collection and analysis of stream-flow data, depends on control of floods, pollution, and channel and reservoir sedimentation. Miami and Muskingum River flood-control projects are outstanding examples. Pollution-control projects of similar scope are under way. Gaging stations need rehabilitation (true for most of country).
Quality of water	Most ground water, and river water in time of low flow, is hard. Water in poorly productive glacial deposits near Lake Erie and in bedrock below stream level likely to be highly mineralized.	Quality data extremely scanty. Geological Survey had made less than 100 analyses of ground water in State and has short-term records of river-water quality for only about 25 stations. Sediment data to be collected on Maumee River, first Geological Survey station in State. Quality data needed especially for ground water in areas where it is not abundant.	

Oklahoma

A semiarid to subhumid State in which water is not sufficiently abundant to be developed or used haphazardly, but in which careful development, based on better hydrologic information than now exists, will be able to meet present and future needs. Use limited by quality rather than quantity in some areas. Surface supply large but poorly distributed in both time and place and highly variable in quality; best in quantity and quality in eastern half. Ground water widely distributed in numerous aquifers, underlying total area of less than half of State, whose occurrence and distribution are known in detail in few areas; quality highly variable. Few highly productive aquifers; especially lacking in most of eastern Oklahoma, where, however, surface water is most abundant. Total ground-water use estimated at 48 million gallons per day (about 55,000 acre-feet) in 1945 and substantially larger now; includes domestic water for about 68 percent of population. Total surface runoff from State about 32,000,000 acre-feet per year, of which 18,700,000 originates in State. Surface-water use in 1949 estimated at 131,000 acre-feet for public supply and industry, 27,000 for irrigation, and 3,800,000 for hydro-power. Flood and sediment problems and low flow in dry season indicate need for storage.

Arkansas River Basin

Northern two-thirds of State. Surface water scarce in west; surplus in east. Large stored supply of ground water in High Plains but recharge limited. Ground water also in alluvium and, in west, in terrace deposits flanking streams which are above stream level and not subject to induced infiltration. Ground water also in Rush Springs sandstone in west, Garber and Wellington sandstones and Vamoosa and Nelagoney formations in center, and Boone formation and Arbuckle group (including Roubidoux formation) in northeast.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
High Plains and rest of Cimarron and Canadian River basins	Low runoff; large storage necessary for use of surface water, limited by deep entrenchment of streams. Cimarron and Salt Fork Rivers cross salt beds in Woods and Alfalfa Counties and largely unusable downstream; Cimarron one of chief contributors of silt to Arkansas River. North Canadian River will be most fully developed stream in State; heavily polluted by industrial waste below Oklahoma City. Local ground-water supply at Enid overdeveloped. Floods and heavy sediment load in main Canadian River. Ground water along North Canadian below Oklahoma City polluted by industrial waste; Shawnee wells abandoned. Heavy pumping from Garber and Wellington formations in Oklahoma City - Norman area but no serious overdevelopment.	Additional data on stream flow and sediment loads and analysis for economical design of storage and flood- and pollution-control projects. Expanded ground-water studies to locate aquifers and evaluate supply in heavily pumped areas; present data largely on a "spot" basis.	Control of silt needed in Cimarron Basin. North Canadian used by Oklahoma City and may be used for Enid, which is also considering ground water some distance from city. Canton and proposed Optima (Hardesty) Reservoirs will control North Canadian River fully; good irrigation possibilities with full development. Interstate compact needed among Oklahoma, Texas, and New Mexico for main Canadian River. Proposed Eufaula Reservoir near mouth would provide silt detention and flood control; erosion control needed in basin. Pollution control needed. High Plains aquifer and terrace deposits yield good water but recharge is from precipitation and is small; careful development necessary to prevent depletion. Alluvium yields large ground-water supplies but relation to quantity and quality of river water must be considered.
Verdigris, Neosho (Grand), Illinois, and Poteau River basins	Floods on all streams. Possible overdevelopment of good water in Roubidoux formation in Ottawa County and adjacent	Study of regional safe yield of Roubidoux formation.	Oologah Reservoir designed to control floods on Verdigris; authorized reservoirs on other streams will control them and provide very large supplies

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
	area in Oklahoma, Kansas, and Missouri. Declines of ground-water levels in Miami and adjacent area (locally over-developed).		for power, navigation and recreation, and irrigation as needed. Coordinated interstate development of ground water in Roubidoux needed. This supply could be supplemented or replaced by surface water, but at considerable cost in areas distant from streams. Among formations above the Roubidoux, the Boone is promising source of ground water, which, however, is harder and more subject to contamination. Limited development of ground water possible from alluvium; additional information needed on occurence and quality of water.

Red River Basin

Southern third of State. Acute problems of water supply for municipalities and irrigation, and flood and sediment control in western part. Considerable surface water available in east. Ground water in alluvium of major streams, terrace deposits and Blaine (?) formation in west, Rush Springs sandstone and Clear Fork and Wichita formations in center, and Trinity group in south-center and southeast.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Red River basin west of Washita River	General shortage of water for all desired uses, especially irrigation and municipal. Irrigation with ground water in Duke area expanding; water from gypsum beds and of poor quality for other uses.	Additional stream-flow data and analysis. Additional ground-water and quality-of-water studies.	W. C. Austin project on North Fork of Red River is only major irrigation project completed so far in State (50,000 acres). Additional water will be needed when irrigation is fully developed. Salt Fork, Elk, Otter, Cache, and Beaver Creeks, and Deep Red Run are possibilities but flow data inadequate for evaluation. Elk City has developed water in alluvium of North Fork of Red River.
Washita River basin	Area of greatest need for water conservation and development in State. Public supplies inadequate or of poor quality at several places, including Clinton, Anadarko, and Chickasha. Floods and sedimentation are serious problems; also flow of mineralized water from gypsum beds into Washita River. Irrigation with water from Rush Springs sandstone increasing rapidly in Pond Creek basin in western Caddo County.	Expanded ground-water studies, especially in regard to municipal supplies. Data on flow of small streams.	Storage reservoirs to increase availability of water for irrigation and municipal supplies and to provide flood control. Erosion control on uplands is improving conditions there but floods will still occur on main streams. Pond (Cobb) Creek promising for additional water of good quality if storage provided.

Oklahoma—Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Eastern part of Red River basin	Water problems less acute, principally floods, and low-flow shortage on small streams. Surface water generally of good quality. Sands of Trinity group yield water of variable quality; pumping of fine sand is a problem.	Additional flow data for small streams. Detailed study of Trinity group (under way in McCurtain County) to determine potential yield; data on proper well-construction methods.	Texoma Reservoir provides flood control, recreation, and power. Storage needed on small streams to provide flood control, and water supply in time of low flow; includes Mountain Fork, Little, Kiamichi, and Boggy Rivers.

Oregon

Streams rather fully appropriated in State as a whole, especially in dry years; additional water can be provided by storage in most areas. Many flood-control and drainage problems. Conflict of interests among irrigation, power, flood-control, navigation, fish, and recreational interests may create shortages even on streams having little consumptive use. Surface water irrigates about 1,200,000 acres; total diversion probably 2,000,000 to 3,000,000 acre-feet per year, net diversion perhaps 25 percent less because of return flow. Ground-water occurrence variable. Large supplies available in some areas but relation to surface water must always be considered. Probably no overdeveloped areas but considerable interference between some wells in Walla Walla, The Dalles, and Prineville areas.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Surface water	Surface water in Alvord Lake basin over-appropriated. Pollution in lower Malheur River, but does not affect irrigation. Flooding in Powder River below Baker and in upper Grande Ronde River. Some flooding on Walla Walla and Umatilla Rivers and on Willow Creek at Heppner. Floods and pollution in Willamette River. Flooding in Umpqua and Rogue Rivers; pollution of Bear Creek. Control and management of Snake and Columbia Rivers for multiple purposes far from complete.	Much additional stream-flow data and analysis for design of the numerous power, flood-control, and irrigation developments proposed; for example, no good records on Willow Creek, where 1903 flood killed 200 people and no flood protection yet provided.	Substantial additional storage possible in most basins. Streams not fully appropriated include Ana River (Summer Lake basin), Wallowa River below Minam, Grande Ronde River below Elgin, lower John Day River (not much irrigable land near river; proposed Clarno Reservoir would provide water for northern Gilliam and Morrow Counties), lower Deschutes River (irrigable land 1,000 feet above river), lower Umpqua River, and Rogue River. Coordinated development of Columbia and Snake Rivers necessary because of interstate and international aspects.
Ground water	Use of ground water not known; small in comparison with surface water. Considerable pumping in Willamette Valley. Milton-Freewater area in Walla Walla Basin, The Dalles area, and Prineville area fully developed. Development of fresh water in sands of Pacific beaches just beginning. Irrigation pumping near Yonna and Summer Lake may be depleting flow of Lost and Ana Rivers, respectively. Ground-water levels about normal according to available records.	Ground-water data adequate for only a few areas; not even reconnaissance data for most of southeastern part of State.	Considerable promise for additional development in the few low-lying or basin areas of State; Willamette Basin is the largest. Dalles-Umatilla lowland is another, but developed near the Dalles. Some basins in south-central and eastern parts of State, including some nearly enclosed fault-block basins such as those in Lake County. Ground water present beneath plateau and mountain areas in rest of State, but mostly not much above stream level and too deep to reach economically except in river valleys. Any large ground-water developments must be considered in relation to streams, which are fed by ground-water discharge in time of low flow. Ground water may be more economical to develop than surface water for many small to moderate uses, particularly for small towns, but data inadequate.

Pennsylvania

About half of 33 trillion gallons of water falling on Pennsylvania runs off in streams and is available for use - about 4,500 gallons per day per capita, yet serious water problems exist in State. Among them are floods like that of 1936 and droughts like that of 1930-31. Stream pollution serious now but excellent progress being made. Data on flow of small streams inadequate. Reconnaissance ground-water studies made for whole State but many detailed studies needed.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Surface-water supplies	Drought of 1930-31 caused severe shortages for many cities having inadequate storage. Use of surface water not known but very large and increasing.	Hydrologic data for small watersheds. More than 90 percent of public surface-water supplies from watersheds of less than 20 square miles.	Many cities have constructed storage reservoirs since 1930-31 and tendency to go to small upland watersheds increasing to avoid use of polluted larger streams. Harrisburg has shifted from Susquehanna River to 22-square-mile Clark Creek basin; Bethlehem from Lehigh River to 17-square-mile Wild Creek basin. State has built six flood-control and recreation reservoirs on streams draining 1 to 37 square miles. Many additional developments possible but data for economical design lacking.
Flood control	Severe floods have damaged many areas in past and still threaten many.	Stream-flow records and analysis for economical design of protection works.	Substantial progress made. Pittsburgh now largely protected; also cities like Wilkes-Barre, Williamsport, and Sunbury which were nearly destroyed by 1936 flood. More than 200 other projects completed in last 5 years; many more needed.
Stream pollution	Pollution widespread in streams from sewage and industrial wastes. Among problem areas are Pittsburgh and many areas in southwestern Pennsylvania, and Philadelphia - Reading, Allentown - Easton, Altoona - Johnstown, Harrisburg - York - Lancaster, Wilkes-Barre - Scranton, Pottsville - Hazelton, Williamsport-Lock Haven, and acid mine waters and coal wastes in anthracite-mining area of eastern Pennsylvania.	Studies of economical pollution-control measures. Quality data adequate only for upper Schuylkill River basin.	Substantial progress being made under State direction. By June 1, 1952, all municipalities and industries are scheduled to put pollution-control measures into operation.
Ground water	Total use (1945) estimated at 100 million gallons per day for public supply, 250 million gallons per day for industry, and 90 million gallons per day in rural areas; substantially larger now. Principal areas Beaver and Allegheny Counties (Pittsburgh and surrounding area), 108 million gallons	Reconnaissance studies made for State. Detailed studies needed in areas of present or prospective development, especially continuing studies in Pittsburgh and Philadelphia areas and new studies in such	Large additional supplies available in glacial gravel in Allegheny and Ohio River Valleys outside heavily pumped part of Pittsburgh and in main valleys of northeastern and northwestern parts of State and along Delaware River above Philadelphia, but location and potential yield of aquifers

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
	per day, Philadelphia area more than 30 million gallons per day, Bucks County 18 million gallons per day. Serious ground-water pollution in Philadelphia area, due in part to induced infiltration from Delaware River. Full development in Triangle area of Pittsburgh; some local overpumping. Problems of mine drainage in anthracite area, both difficulty and expense of draining and formation of acid waters that pollute streams. Interference between ground-water developments in Philadelphia and Camden, N. J. Pumpage may be approaching perennial yield in large area of only moderately productive rocks, mainly Triassic, tapped for industry and public supply north of Philadelphia, in Bucks and Montgomery Counties.	areas as Altoona, Johnstown, Harrisburg, Bethlehem, and Allentown. Studies of relation of ground-water levels to stream flow to assist industries depending on low flow, such as studies made by Pennsylvania Power Co. using Geological Survey data; some work being done at Forest Service experiment station in Pocono Mountains; work needed in Schuylkill, Lehigh, and Brandywine Basins. Occurrence of water in limestone and in creviced rocks in southeast. Intensive study in Morrisville area where new large steel plant is proposed. Artificial-recharge studies in belt of Triassic rocks to determine possibility of arresting declines at such places as Lansdale. Location and evaluation of productive sand and gravel aquifers in northwest and northeast. County-by-county inventories of ground-water uses, future needs, and possible sources, as in Allegheny, Beaver, Armstrong, Bucks, Montgomery, Philadelphia, Chester and Delaware Counties.	poorly known. Small to moderate supplies available elsewhere but erratic occurrence of productive rocks necessitates much research and detailed local studies. Ground-water supplies can be developed more economically than surface-water supplies in many places for small towns, industries, and supplemental irrigation, but only on basis of more detailed data than now available.

Rhode Island

Industrial activity per square mile of area greatest in Nation. Water resources are most valuable resource and are adequate if properly developed. Problems include local shortage of water supply, stream pollution, and minor flooding.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ground water	Local areas of heavy pumping scattered throughout State but no serious overdevelopment noted. Local declines at Providence and Woonsocket, but involving only closely spaced wells of individual industries. Total pumpage a few tens of millions of gallons per day, including 14.5 million gallons per day for public supply in cities and towns over 1,000.	Detailed studies made in Woonsocket, Pawtucket, and Providence areas; needed for rest of State to outline ground-water potential. Study of possible salt-water encroachment along Woonasquatucket River in Providence.	Ground water used by many industries and small communities and much further development possible if done properly. Best sources are gravel-filled valleys, including many not now occupied by streams, particularly in northeastern, central, and southern parts of State.
Stream pollution	About 85 percent of municipal sewage but only 10 to 15 percent of industrial wastes receive treatment. Grossly polluted streams include stretches of Blackstone River below Woonsocket and Pawtucket, the Moshassuck River, and short stretches on other streams.	Methods for economical waste treatment, especially at textile plants not discharging waste into municipal systems.	Substantial progress being made. Blackstone Valley District Sewer Commission formed in 1947. New trunk line sewer and treatment plant under construction to serve municipalities and industries in the lower Blackstone Valley. New treatment facilities planned for Providence, East Providence, Cranston, Warren, and Newport.
Surface-water supply	Providence water supply used by half of population (386,000); from Scituate Reservoir on North Branch Pawtuxet River. Designed safe yield 85 million gallons per day; use in 1949 about 37 million gallons per day; no problem. Pawtucket supply short in 1949. Bristol-Warren-Barrington, East Providence, Woonsocket, and Newport supplies probably inadequate for future needs. Total use of surface water for public supply in State (for towns over 100) was 67.6 million gallons per day in 1949.	More stream-flow data, especially for small basins, to guide future surface-water developments for all uses, including pollution control.	Supplementary ground-water supplies developed for Pawtucket and for Bristol-Warren-Barrington. Ground-water source located for East Providence but not yet developed. Increased storage on South Branch Pawtuxet River possible for future needs, including power. Headwaters of Pawcatuck River also promising but remote from highly developed part of State.
Floods	Relatively minor problem. Greatest flood in 1886. Lesser floods of 1927, 1936, and 1938 caused damage amounting to only 1.2 percent of total for New England.		Some flood control desirable for lower Pawtuxet Basin but not thought economically justified. Many swamps and ponds, and reservoirs intended for other uses, provide considerable protection.
Irrigation	Minor so far but increasing. About 53 million gallons used in 1949 from 135 ponds fed by precipitation and ground water, 14 ponds and reservoirs fed by precipitation and surface runoff, and 3 river sources.	Data on economical sources of ground water and surface water. Studies to determine safe yield of ground-water reservoirs.	Greatly increased development of supplemental irrigation possible, as in much of humid East.

South Carolina

Large available water supply but basic data very inadequate. Problems include floods, silting of reservoirs, stream pollution, local overdraft or salt-water encroachment in ground-water reservoirs, and problems of chemical quality of ground water. Total use of ground water in State estimated at 70 million gallons per day; no estimate of surface-water use.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Coastal Plain	Large use of surface water for industries, public supply at Charleston and Orangeburg, and power at Santee-Cooper project. Stream pollution not serious so far, but salinity of coastal stretches of streams limits usefulness. Surface water of good chemical quality but high in color. Flooding widespread because of flat slopes and inadequate channel capacity of streams; slow drainage leads to prevalence of malaria in some areas. Some silting of reservoirs. Ground water high in iron in central coastal plain and in fluoride near coast. Possible local overdraft at Georgetown and near Florence. Salt-water encroachment in Georgetown, Beaufort, and Charleston areas.	Stream-flow records of short length and inadequate coverage. Ground-water studies needed for whole area, including study of iron and fluoride and possible sources of good water in affected areas; safe yield of ground-water reservoirs in developed areas, particularly near coast.	Flood control and drainage needed for reclamation of land and malaria control. Large additional ground-water supplies available; wells average 300 gallons per minute and yield up to 2,000, but occurrence of aquifers inadequately known. Large expansion of supplemental irrigation with surface water and especially ground water possible.
Piedmont	Most heavily populated and developed part of State. Large surface-water use for industries, for public supply of most cities, and for power. Stream pollution becoming more serious. Extensive flooding in valleys and silting of reservoirs, especially those of power plants. Ground water used for small towns and many industries; yields of wells less than in Coastal Plain.	Additional stream-flow data for flood and pollution control and proposed power projects. Detailed ground-water studies, especially of occurrence of water in the hard rocks and possibility of more successful prediction of well locations for maximum yields. Temperature data for surface water and ground water.	Considerable additional use of both surface water and ground water feasible if based on better data.
Mountain area	Little use of water. Considerable flooding in valleys.	Stream-flow data for proposed power and flood-control projects. Occurrence of ground water in alluvium in valleys.	Large additional development of surface water possible, and development of ground water in valleys if areas of thickest alluvium are located.

South Dakota

Semiarid to subhumid State of generally deficient water supply under natural conditions. Most of precipitation occurs in growing season, permitting productive agriculture but being dissipated by evapo-transpiration. Principal local source of surface runoff and ground-water recharge is melting of winter snowfall. Generally low storage capacity of ground-water reservoirs and low stream flow in summer mean that substantial use of surface water depends on impounding water. Eastern part of State poorly drained and lacking in good reservoir sites because of flat slopes and large reservoir losses. Missouri Basin development will provide substantial additional water and improve situation considerably.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ground water	Ground-water sources not fully exploited and potential yield unknown. Ground water occurs in alluvium along Missouri and principal tributaries, in glacial deposits in eastern part of State, in shallow sandstones in northwest, in some rocks near Black Hills, and in the Dakota sandstone beneath most of State (more than 2,000 feet deep in western part except beneath major stream valleys and in vicinity of Black Hills). Ground water is source of 70 percent or more of domestic, stock, municipal, industrial, and railroad needs. Ground water is generally of substandard quality. Dakota sandstone artesian pressures reduced by waste from flowing wells (presently estimated at more than 20,000 acre-feet per year).	Detailed ground-water studies needed in all parts of State to locate productive aquifers and evaluate yield in areas of present or proposed development and to determine possibility of waterlogging from future irrigation. Study of ground-water recharge and movement especially needed in Black Hills area where streams lose water to exposed bedrock formations. Need for detailed studies being partly satisfied by current studies under Missouri Basin development program.	Ground water available for many future developments, especially in alluvium of Missouri River and in some bedrock formations near Black Hills. Substandard quality and high cost of development will cause many problems. Drainage needed in some areas, as Putney Slough and Sand Lake area of James River Valley. Waste from flowing wells should be reduced. Future irrigation will increase ground-water recharge and improve quality in certain areas but may cause waterlogging and create new demands for domestic and other uses in areas where local supply will not be improved by irrigation. Application of irrigation waters should be within limits of control by economical drainage measures.
Surface water	Floods in spring and inadequate dry-season supply. Some streams draining Black Hills have better sustained flow; one such stream is Rapid Creek but its low flow is fully utilized. Even with maximum development of surface water there will not be enough for all desired uses.	More stream-flow records, especially on small streams, to guide future municipal and irrigation developments and flood-control projects. Especially important to permit most efficient use of water in view of over-all deficiency in water even with maximum development.	Additional storage reservoirs even on Black Hills streams, including Rapid Creek. Relatively few large reservoirs so far; one on Belle Fourche River, built in 1906, was first large one. Multiple-purpose reservoirs on Cheyenne River at Angostura and Grand River at Shadehill nearing completion; others being studied. Reservoirs being constructed on Missouri at Oahe and Fort Randall will control river completely and provide much additional water, including water for a million acres in James River Valley. Need for careful integration of all water developments to provide maximum supply and minimum waste.

Tennessee

Large over-all water supply but many problems of flood control, pollution, and water supply remain, even in places within Tennessee Valley where much work toward control of the river for flood prevention, navigation, and power production has been completed. Central Basin is area most seriously deficient in ground water and dry-season flow of streams. Basic data inadequate for ground water and smaller streams.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Blue Ridge	Many springs but only small ground-water supplies available from wells. Chief function of ground water is in sustaining low flow of streams. Area probably will never be highly developed for ground-water supply. Surface water used in Elizabethton and Copperhill areas; low flow of streams supplying these areas supplemented by surface storage most of the time. Pigeon, French Broad, and Ocoee Rivers polluted and contaminated.	Data on flow of small streams.	Large supplies of good water, cold most of year, available from streams, especially when low flow is supplemented by storage. Pollution control needed.
Ridge and Valley area	Ground water mainly in calcareous rocks; quantity highly variable from place to place. Heavy use at Chattanooga, Knoxville, and Elizabethton. Ground water hard and subject to pollution as in most areas of cavernous limestone. Serious problems of mine drainage; in some cases cost is so high as to limit ore production. Industrial use of river water has created pollution and contamination problems, especially at Bristol, Harriman, Kingsport, Knoxville, and Chattanooga.	Detailed ground-water studies, especially of occurrence of water in limestone in relation to water-supply and mine-drainage problems. Data on small streams.	Large additional supplies available from surface water and properly located wells if based on adequate data. Pollution control needed.
Cumberland Plateau	Stream flow poorly sustained at low flow. Area thinly settled. Ground water available for domestic use. Local shortages of water for public supply.	Almost no ground-water data available. Data on small streams needed.	Ground water probably available for some municipal and industrial uses but occurrence not well understood. Storage possible to increase low flow of streams.
Highland Rim area (surrounding Central Basin)	Ground water appears to be available in sufficient quantities for domestic and small industrial use. Mineralized water encountered at depth. Stream flow poorly to well sustained. Ground water probably polluted locally as in other limestone areas. Lower Piney River is seriously polluted. There is also pollution on the main Cumberland River and on Sulphur Fork of Red River.	Ground-water and surface-water data to guide increasing development, as for Air Corps research center at Tullahoma, where estimated use may approach total flow of Elk River.	Considerable additional development may occur, and should be based on better data to provide water supply, flood protection, and pollution control at feasible cost.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Central Basin	Ground water generally scanty, but domestic supplies generally available. Critical shortages of water for some public supplies and difficulty in making economical developments. Stream flow poorly sustained. Flood-control problems on Cumberland, Duck, and Elk Rivers at towns along their courses, such as Shelbyville, Columbia, Fayetteville, and Nashville. Few good dam sites available on smaller streams. Pollution by sewage and industrial waste below principal towns, most serious at Columbia on Duck River and Nashville on Cumberland River. On the whole, the most critical area in State as regards availability of water at reasonable cost.	Ground-water data meager except for some local areas; imperative need for additional information. Small streams almost entirely ungaged; data needed for guiding storage projects, especially because most economical design is of extreme importance.	Flood and pollution control, additional developments for public water supply.
Mississippi Embayment	Most productive ground-water area in State. Ground water of good quality except for iron. Large developments few except at Memphis (120 million gallons per day), and no apparent areal or regional depletion in spite of declining water levels at Memphis. Relatively little use of surface water, but problems of floods, pollution (especially Wolf River in Memphis area and Forked Deer River at Jackson), drainage, and soil erosion.	Continuation of studies in Memphis area to evaluate perennial yield under given conditions of pumping and water levels. Studies in rest of area to evaluate aquifers. Data needed on flow of small streams.	Large ground-water and surface-water supplies remain available for development and should be developed on basis of better data than now available.

Texas

Average annual precipitation ranges from 8 inches in the west to 55 inches in the east; surface runoff from less than 0.25 inch to nearly 20 inches. With coordinated development of surface- and ground-water resources in east Texas, water of satisfactory quantity and quality will be more than ample for foreseeable needs, but storage facilities generally necessary for surface-water supplies. In west Texas water resources, when properly developed, ample for foreseeable needs in localized areas but generally deficient in quantity and in some places always deficient in quality even if developed. Use of water large and may double in next decade. Additional data needed on surface-water flow, quality, temperature, and sediment, particularly in small streams, and on ground water to guide foreseeable developments. Total quantity of water used, excluding hydropower, estimated at 7,140 million gallons per day in 1949, about three-fifths surface water and two-fifths ground water; about 8,000 million gallons per day used for hydroelectric power and reused in part for other purposes, remainder available for future uses. Corrective measures and further development require public education for efficient utilization.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Northern High Plains (north of Canadian River)	Total supply, with minor exceptions, comes from wells. Surface runoff small and intermittent, surface storage limited to minor activities. Large amount of stored ground water but recharge small. About 8 million gallons per day pumped from wells to irrigate 9,000 acres in northwestern Dallam County; pumpage in center of district exceeds recharge. About 50 million gallons per day pumped in Sunray-Etter, Herring, and Kay industrial areas but no serious depletion of storage.	Evaluation of ground-water supply.	Creation of local ground-water conservation district being considered under recent State legislation. Large quantity of stored water available, but perennial yield small.
Southern High Plains (including the Canadian River)	Total supply, with minor exceptions, now comes from wells. Surface runoff small except for Canadian River. Storage limited to minor activities. About 1,050 million gallons per day (1,155,000 acre-feet) pumped from wells in 1949, about 97 percent to irrigate 1-2/3 million acres of land. Recharge roughly 50,000 acre-feet per year in irrigated district. Average annual recharge only about 5 percent of current pumpage. Total storage estimated at 150,000,000 acre-feet.	Detailed studies to get better estimates of recharge and of local and regional storage capacity; records of pumpage and depletion of storage.	(See discussion in text.) Storage on Canadian River being considered for municipal and industrial supply. Creation of local ground-water conservation district being considered under recent State legislation.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
El Paso area in Texas	Principal municipal and industrial supplies obtained from wells, surface water from Elephant Butte Reservoir supplies about 400 million gallons per day for irrigation of about 80,000 acres of land. Total pumpage from deep wells in El Paso area and in Juarez, Mexico, about 22 million gallons per day in 1948. Storage reduced by pumping in part of "Mesa" immediately north of city. Water in artesian aquifers subject to salt-water encroachment.	Studies of available storage beneath Mesa; of occurrence of salty water in valley and methods to reduce encroachment; of availability of flood waters for artificial recharge of ground water.	More ground water available beneath Mesa farther north. River water and shallow ground water, though of poor quality, being treated at El Paso waterworks built in 1943. Additional flood water appropriated by El Paso and storage anticipated. Foreseeable demand exceeds potential supply.
Salt Basin, Hudspeth and Culberson Counties	Total supply, with minor exceptions, comes from wells. Closed basin in a semi-desert region of western Texas into which streams discharge small quantities of water only after heavy rains. Development of stored ground water recently begun for irrigation; in 1949 about 16 million gallons per day pumped for 6,000 acres in Dell City area near New Mexico line and about 14 million gallons per day in Lobo Flats area in south.	Studies of recharge, stored ground water, and possibility of encroachment of salt water from "playa" lakes in middle of basin.	Perennial ground-water yield may be small and may already be exceeded locally. May be another area of low recharge. Some additional withdrawals possible in undeveloped areas.
Pecos Valley	Surface supply fully appropriated for irrigating 32,000 acres. Pecos River water salty but satisfactory if enough is applied to leach salts from soil. Ground-water development increasing rapidly in scattered areas; water highly mineralized in some areas; about 88,000 acres irrigated. Springs at Fort Stockton and Balmorhea yield about 53 million gallons per day, fully utilized. Pecos area believed overdrawn. Pumping will eventually affect flow of springs.	Studies to determine maximum yield of ground water in all parts of basin and relation to flow of springs. Duty of water for irrigation.	Water needs exceed resources. Need for reduction of water consumption by "phreatophytes" along streams and canals; for rehabilitation of canal systems. Creation of ground-water conservation district in Pecos area being considered under recent State legislation.
Winter Garden area, Dimmit, Zavala, and Maverick Counties	About 17,000 acres irrigated from Nueces River and tributaries. About 50 million gallons per day pumped from wells, 98 percent used to irrigate 50,000 acres. Pumpage about twice recharge.	Stream-flow data for small streams for economical design of storage reservoirs. Possibility of artificial recharge, and additional geologic studies.	Future water needs will exceed resources. Moderate quantities of surface water available by additional storage on Nueces River and tributaries.

Texas—Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Lower Rio Grande Valley, principally in Hidalgo, Cameron, and Willacy Counties	About 600,000 acres irrigated from unregulated flow of Rio Grande, requiring about 1,100 million gallons per day from the river. Water shortages occur during most years. Lands becoming waterlogged and mineral concentration of water increasing. Municipalities use about 11 million gallons per day from surface-water sources. Ground water of good quality not available in large quantities.	Comprehensive hydrologic study of the irrigated area, including study of chemical quality of water, for improving drainage. Duty of water and most effective method of application not fully known.	The Rio Grande, an international stream, is principal source of water for future developments. Average flow about 4,600 million gallons per day. Through treaty, Mexico may use about half of total flow. Construction of Falcon Reservoir near Zapata will begin soon. It will partly regulate flow and relieve most water shortages for currently irrigated areas. Two other upstream reservoirs proposed for future. Proper regulation of flow will permit some expansion in irrigation, municipal, and industrial development. Need for practice of most conservative type of distribution and application of water to prevent waterlogging.
Atascosa County	About 300 acres irrigated with surface water. Average runoff about 100 million gallons per day; flow erratic. About 4,000 acres irrigated from wells. Current draft about 14 million gallons per day, about 40 percent by uncontrolled flow. No overdevelopment apparent. Salt-water-encroachment possibilities small. Surface- and ground-water resources capable of further development.	Study of safe yield of ground water. Basic data on water resources of small streams.	Proper storage would permit expanded use of surface water. Additional development may be possible from adequately spaced wells, and by utilizing all water from flowing wells.
San Antonio area, Bexar County and adjacent area	Medina Reservoir, with capacity of 82.6 billion gallons, supplies water for irrigation of about 20,000 acres. Ground-water reservoir in Edwards limestone yields about 130 million gallons per day to wells in Bexar County and supplies springs yielding about 400 million gallons per day between Uvalde and Austin, including 200 million gallons per day at Comal Springs, New Braunfels, which supplies most of low flow of Guadalupe River and is used for power and irrigation.	Comprehensive hydrologic studies to determine water supply of all reservoirs and relations of ground water and surface water. Basic data on water resources of small streams.	Integrated development of surface- and ground-water resources. Other than Medina Reservoir, facilities have not been built to utilize surface-water resources. No major developments can be sustained but development of runoff on selected small streams would permit expanded uses of surface water.
Coastal Plain	About 560 million gallons per day of ground water and 1,525 million gallons per day of surface water used in 1949 in upper part, from Victoria to Sabine River; and about 30 million gallons per day of ground water and 516 million gallons per day of surface water in lower part, extending to but not including Rio Grande. Danger of pollution by oil field waste in San Jacinto,	Continuing ground-water studies to evaluate ground-water supplies, especially in pumped areas as draft increases. Analysis of surface-water records to permit economical design of water-supply and other surface-water projects.	Total demand probably will double in next decade. Probably not more than 10 percent of ground-water reservoirs are being drawn on heavily. Large reserves in unpumped parts of area, particularly in a belt 40-50 miles wide extending from Victoria County on the Guadalupe to Jasper and Newton Counties on the Sabine. Limit of pumping is largely a matter of determining whether pumping from greater depths is cheaper than importing surface water, or ground

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
	Trinity, Neches, and Sabine Basins, especially during periods of low flow. Also salt-water encroachment from Gulf in above-named rivers at low flow. Water from Brazos River has been developed to permit reducing draft on wells in Texas City-Galveston area and Freeport-Velasco area; Possum Kingdom Reservoir (capacity 241 billion gallons) on Brazos River 600 miles upstream aids in stabilizing that river's flow across the Coastal Plain. Buchanan and Marshall Ford Reservoirs (combined capacity of conservation storage about 670 billion gallons) on the Colorado River in central Texas stabilizes flow of that stream across Coastal Plain. In addition to the production of power, these rivers supply irrigation water for about 400,000 acres of rice on the Coastal Plain. Ground water of poor quality south of Corpus Christi and in most of Chambers County and southern Jefferson County. Only areas of known overdevelopment are Texas City and the Alta Loma well field in Galveston County; Pasadena industrial area in Harris County and Freeport-Velasco area in Brazoria County may be overdrawn. Danger of ground-water contamination in oil-field areas. Ground-water decline in Katy rice-growing area west of Houston, but not believed important. In Orange area supply of fresh ground water is limited. Heavy pumping in Lufkin-Nacogdoches area has lowered water levels but ground-water reservoir thought not to be overdrawn.	Study of possibilities of ground-water contamination in oil-field areas. Continued detailed studies in Houston-Pasadena-Ship Channel-Baytown area, where more ground water is pumped for municipal and industrial uses than anywhere else in Nation except western Long Island. Studies in Lufkin-Nacogdoches area, most heavily pumped in northeast Texas. Studies of surface water available in small creeks.	water from adjacent lightly pumped areas. Total surface runoff (including Sabine and Rio Grande) averages about 11.3 billion gallons per day. Houston has developed an industrial water supply from unregulated flow of San Jacinto River, now furnishing 30 million gallons per day to Pasadena area, and is planning a large storage reservoir to increase supply. Additional large supplies are available from Sabine, Trinity, Neches, Brazos, and Colorado Rivers. In addition to existing reservoirs, the Corps of Engineers is now constructing eight major reservoirs in the Brazos, Trinity, and Neches watersheds that will further regulate the water supplies of these streams on the Coastal Plain. State river authorities and other agencies are planning the construction of other flood-control and conservation reservoirs.

Texas—Continued

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Dallas-Fort Worth and adjacent area	Large area extending from Hill County to the Red River. Ground-water reservoir overdrawn in Fort Worth area and may be overdrawn, though less seriously, in the region as a whole. Total pumpage from wells about 34 million gallons per day, about 16 million gallons per day for industries at Fort Worth and Dallas. Bridgeport, Eagle Mountain, Lake Worth, Lake Dallas, and Mountain Creek Reservoirs, having combined capacity of 251 billion gallons, provide water for industrial and most municipal uses of Dallas and Fort Worth. In 1949 Dallas used an average of 52 million gallons per day, and Fort Worth used about 30 million gallons per day.	Safe yield of ground-water reservoir under various conditions of development. Basic hydrologic data on small streams, chemical quality and temperature investigations.	Four more flood-control and storage reservoirs with capacity totaling 1,600,000 acre-feet are under construction by Army Engineers. Ample water will be available and there are still more storage possibilities if needed. However, individual cases may involve economic hardship where wells must be abandoned.

Utah

State prevailingly arid or semiarid and contains much more arable land than can be irrigated with present and prospective water supplies. However, ground water in many valleys of Southwestern Bolson province (Great Basin) is undeveloped or only partially developed, and these potential supplies and the unused part of the Utah share of Upper Colorado River supply will permit developments substantially larger than the present. Surface-water data greatly inadequate for increased developments now proposed. Ground-water studies made in only a few basins and must be expanded greatly if ground-water potential is to be realized. Quality and sediment data meager for almost whole State; will be essential to successful developments. State ground-water law of 1935 has assisted in orderly development, and has been invaluable in preventing overdevelopment.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Southwestern Bolson province	Surface-water available at time of need is fully appropriated. Local overdevelopment probably exists in part of Escalante Valley. Problems include extensive waterlogging; floods, including destructive mud flows; present or possible interference between ground-water and surface-water use; occurrence of salty water; waste of water from flowing wells, etc. Present beneficial use of ground water more than 200,000 acre-feet per year, but accurate data not available; demand increasing rapidly in basins at east edge of the province.	Surface-water data inadequate for practically all of proposed and possible developments. Ground-water studies needed in all basins. Preliminary studies made in Cedar City, Parowan, Escalante, Pavant, northern Juab, Tooele, Jordan, and Cache Valleys, Bountiful district and Ogden portion of Weber Delta district of East Shore area, and northern part of Utah Lake Valley. Quality-of-water data meager. Ground-water potentialities should be studied thoroughly before detailed plans are made for large trans-basin diversions into the valleys, to insure most beneficial use of all water available. Fairly extensive observation-well program in operation since 1935 will be of great value in future studies and in guiding increased development. Virtually nothing is known of water resources of the very dry valleys in the extreme western part of the State, and in the Salt Lake Desert and the adjacent Skull and Dugway Valleys.	The principal surface-water developments that appear to be practicable include surplus Bear River supply of 750,000 acre-feet per year wasting into Great Salt Lake (distribution among Utah and adjacent States should be determined by compact); Weber River project to make about 300,000 acre-feet per year of snow-runoff water available; and proposed Central Utah project to divert 600,000 acre-feet per year from Colorado River basin. Basins that may be capable of some further ground-water development (though a few are locally overpumped) include Beaver, Blue Springs, Cache, Cedar, Curlew, Goshen, Grouse Creek, Jordan, Juab, Lower Bear River, Park, Parowan, Pavant, Rush, Snake, Tooele, and Utah Lake Valleys, Sevier Desert, and the East Shore area. Water wasted by man or by evapotranspiration or unused stream flow into dry or salt lakes amounts to considerably more than a million acre-feet per year (including Bear River surplus), much of which could be salvaged by building storage reservoirs, ground-water pumping, elimination of phreatophytes, and control of pollution that makes some of surface-water unusable. Coordinated development of ground and surface water with comprehensive knowledge of quality will be essential. Drainage needed in Utah Lake, Jordan, Tooele, Escalante, Beaver, and Lower Bear River Valleys, Sevier Desert, and East Shore area.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Montana-Arizona Plateau Province	Ground-water supplies small except in the Uinta Basin and a few valleys. The Green, Colorado, and San Juan rivers carry large amounts of water, chiefly from outside the area, across the plateau. Soils generally thin, and excessively alkaline in many areas. Substantial ground-water developments in Central Sevier, Sanpete, and Fremont valleys. Colorado River and San Juan River areas in southeastern Utah are poor ground-water areas, even stock and domestic supplies being difficult or expensive to obtain in many places. Only irrigable land is along Colorado River and its larger tributaries.	Almost nothing is known of ground water in this large area, and very little of surface water except the flow of large streams. Preliminary studies of ground water have been made in Sanpete Valley and in the Ashley Valley portion of the Uinta Basin. A recent hydrologic reconnaissance of Green River shows that important possibilities may exist.	State plans to divert much of Upper Colorado River supply allocated to Utah from this province to the Southwestern Bolson province. There are some potentialities for ground-water development, as in the Upper, East, and Central Sevier, Sanpete, Fremont, and Grass Valleys, and the Uinta Basin. Drainage needed in Sanpete, Central Sevier, and Castle Valleys. Ground-water prospects in Castle Valley not promising.
Northern Rocky Mountains province	Area contributes water to Southwestern Bolson and Montana-Arizona Plateau provinces. Little water used in area itself, except for municipal supply for Ogden, from artesian wells covered by water of Pineview Reservoir in Ogden Valley, and some use in Bear Lake Valley.	Very little known of ground water. Preliminary study made in Ogden Valley. Considerable stream-flow data available, but only a fraction of that needed for proposed development.	Area includes several intermountain valleys or basins, some of which have some ground-water possibilities. Included are Ogden, Morgan, Heber, Kimball, Upper Bear River, and Bear Lake Valleys.

Vermont

Large potential water supplies and relatively light use. Precipitation of 38 inches and runoff generally from 20 to 30 inches make large surface supplies available. Public supplies serve most industries, relatively few developing their own thus far. Public-supply use about 30 million gallons per day of surface water and 6 million gallons per day of ground water for 61 percent of population. Remainder uses largely ground water for domestic use. Chemical quality of water generally good. Some problems of flood control and pollution. Basic data on surface water needed for small basins for design of small dams, culverts, etc. Very little information available on ground water.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ground water	Small supplies for domestic use available from consolidated rocks and from glacial drift on uplands. Larger supplies from glacial deposits in valleys. Use not large but increasing. No declines reported except temporary ones in droughts, which have affected many shallow wells on uplands.	Basic data of all types. Very little information is available.	Largest supplies at shallow depth in glacial gravel in valleys of Connecticut River and tributaries, Lamoille River, and stretches of Winooski, Poultney, and Hoosic Rivers and Otter Creek. Trend toward deeper domestic wells in bedrock to avoid shortage in drought.
Stream pollution	Most sewage discharged untreated but dilution generally adequate. Pollution at St. Albans, Manchester, and Brattleboro sufficient to interfere with recreational uses.		Primary-treatment plants built at St. Albans and Manchester; needed at other cities. Chlorination during swimming hours at Brattleboro. State has reserved all bodies of water used for public supplies, including tributaries, and all others larger than 20 acres, including tributaries.
Floods	Floods of 1927, 1936, and 1938 caused damages of $62,100,000 and, in 1927, loss of 84 lives. Flooding common in valleys but not as serious as in other parts of country.	Surface-water data for economical design of future projects.	Three flood-control reservoirs built in Winooski Basin and one in Connecticut Basin by Army Engineers. Six more to be built in Connecticut River basin. Other needed projects depend on economic feasibility. Power reservoirs provide considerable flood protection.
Power	Hydro-power development considerable (173,299 kilowatts installed capacity in 1949), plus some steam and internal-combustion. About 220,000,000 kilowatt-hours of power imported in 1948.		Projects considered at Waterbury Dam, Boulton Falls, and American Woolen Mills on Winooski River, on Connecticut River below White River and near junction, and on Moose River near Victory. Project under construction at Wilder Dam on Connecticut River.

Virginia

Large over-all water supply. Problems include shortages in droughts and as a result of greatly increasing demand; flood and sedimentation problems; and stream pollution. Basic data inadequate for economical design of many projects proposed for construction in near future. Use of water for municipal and industrial purposes about 1.6 billion gallons per day, about 90 percent surface water.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Coastal Plain	Local heavy withdrawals of ground water for industrial use, particularly south of James River. Ground water used by most small communities and for almost all rural uses. Pumpage of 7 million gallons per day at Franklin has lowered water levels for 20 miles, but area not overdeveloped. About 6 million gallons per day pumped at West Point, and 2 million gallons per day at Hopewell in summer. Difficulty in getting adequate water for towns and industries in some areas, such as northern part near Washington, and in southeastern part where most of ground water is brackish. Low-water flow of streams small and storage difficult because of flat gradients; streams brackish far inland in time of low flow.	Reconnaissance ground-water studies made in most of Coastal Plain and detailed studies in a few areas; needed in all other areas of heavy pumping. Test drilling and pumping tests needed to outline productive aquifers, particularly in northeastern part of area. Quality data inadequate to show character of water in deeper beds in northeastern part of area, not developed much to date.	Large additional ground-water withdrawals possible in central and northeastern parts of Coastal Plain, including parts of Eastern Shore. Large developments of good water in Norfolk-Hampton Roads area must be made in areas of proved supplies such as between Franklin and Bacons Castle. Development farther east and southeast must be cautious to avoid salt-water encroachment.
Piedmont Plateau	Relatively small water supplies available from the hard rocks of the province for domestic use and small towns and industries. Sustained flow of streams higher than in Coastal Plain and storage possibilities better.	Research on occurrence of water in the hard rocks, to permit better prediction of successful well sites. Quality of water in rocks of different types; few data available.	Large additional developments must be made from surface water, but a moderate increase in pumping from wells may be possible and there is promise of larger yields from carefully located wells.
Blue Ridge	Water needs are small, chiefly for domestic use, and likely to remain so. No serious problems except occasional floods and need for preventing pollution of streams at low flow.		Some possibility of obtaining limited quantities of ground water locally in thin alluvium of mountain streams, if needed, at lower cost than filtering surface water.
Valley and Ridge area	Considerable ground-water development at Roanoke (10 million gallons per day or more), Waynesboro (20 million gallons per day or more), and Elkton. No overdevelopment known. Stream flow well sustained, largely because of ground-water flow from cavernous limestone.	Research on occurrence of water in limestone, dolomite, and shale to permit successful well location and construction. Few data on quality of water available.	Large industrial expansion probable in southwestern part of area. Both ground water and surface water are available. Occurrence of water in the rocks somewhat erratic probably because of variable stratigraphy and structure; more detailed information needed on both quality and quantity of water.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Appalachian Plateau	Includes only small area in southwest. Ground water not abundant, low flow of streams poorly sustained. Water short in droughts unless storage provided.	General information on ground water, and on flow of small streams to aid construction of reservoirs where needed.	Demand small and likely not to increase greatly; however, observation wells needed near areas of proposed reservoirs for recharge and quality studies.
Stream pollution and floods	Pollution has been serious on James, upper Roanoke, South Fork Shenandoah, and North Fork Holston Rivers, and locally elsewhere. Flood damage on main streams and certain tributaries.	Surface-water data for design of combination flood- and pollution-control reservoirs. Few data on sediment in streams available; no sediment-sampling stations in State.	Substantial progress in pollution control being made by Virginia State Water Control Board, though much remains to be done. Army Engineers propose combination reservoirs for flood and pollution control and increased low flow for water supply. Erosion control needed, especially in some areas in Piedmont.

Washington

Large over-all water supply, with surplus in west and local or regional deficiency in east. Runoff ranges from less than half an inch in east-central part to 20 inches in northeast corner and 40 to 150 inches in Cascades and along coast. Reservoirs east of Cascades have total usable capacity of 7,101,500 acre-feet, of which 5,975,700 is used for power. Consumptive use of water from streams (depletion) east of Cascades about 1,410,000 acre-feet per year. Use of surface water for cities and industries in State more than 275,000 acre-feet per year. Ground water supplies most smaller cities, many industries, and irrigation; use is more than 300,000 acre-feet per year in the 13 principal areas of use. Large additional developments of ground water and surface water can be made, but mutual interference and interstate and international aspects must be considered. Problems of dry-season shortage, floods, pollution, and reservoir sedimentation. Irrigation in eastern part of State predominantly from surface water; in ultimate irrigation development of western part ground and surface waters probably will be used to about the same extent. State law requires that sufficient water for maintenance of fish life must be left in the streams.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Northeastern area	Spokane River is most heavily used stream, for municipal, industrial, power, and irrigation use. Large ground-water reservoir in and northeast of Spokane Valley adds about 750,000 acre-feet per year to river.	Studies of hydrology of river, under present and proposed future conditions. Data needed on Little Spokane and Colville Rivers and on ground water in their basins and along Columbia and Pend Oreille Rivers.	Major diversion proposed in Idaho. This and effect of proposed increased storage in Lake Pend Oreille will change regimen of Spokane River and necessitate some changes in present uses. Area in Washington not likely to become critical if developments are based on sound hydrologic data, however. Ground water available along Columbia, Colville, Pend Oreille, Spokane, and Little Spokane Valleys; also west of Spokane, but effects of development on stream flow unknown.
North-central area	Much irrigation with surface water practiced in Okanogan Basin and some in Colville Indian Reservation, but much more could be done. Some ground-water development (about 8,600 acre-feet per year) in Lower Okanogan area.	Very little information on availability and relationship of surface water and ground water.	Ground water available along Okanogan River, may be available elsewhere but data not available.
East-central area	Considerable irrigation practiced; to be expanded by 1,000,000 acres in Columbia Basin Project. About 45,000 acre-feet per year of ground water pumped for irrigation in Quincy Basin. Quincy-Winchester area about at maximum yield. Also heavy pumping in Moses Lake area.	Effects of new diversion on flow of Columbia River and tributary streams and on ground water; ground-water studies especially needed.	Increased irrigation with Columbia River water will raise water table, making increased supplies available and halting water-level decline at Quincy, but will create water-logging problems.
Central area west of Columbia River	Large irrigation developments from surface waters, particularly in Yakima Basin where depletion is about 1,000,000 acre-feet per year and more water is needed, yet critical drainage problems have developed. About 25,000 acre-feet of ground water per year now pumped in Yakima area.	Surface-water data for design of storage reservoirs to supplement summer supply; ground-water studies, especially in Yakima Basin, to determine feasibility of drainage and supplemental irrigation by pumping from wells.	Use of ground water in Yakima Basin and of both ground water and surface water in others can be increased, but basic data necessary for economical developments. Ground water believed to be available in Ellensburg and Wenatchee areas. Increased irrigation in Yakima-Sunnyside area will depend largely on ground water. Wenas and Ahtanum Valleys and others might be helped by artificial recharge.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Southeastern area	Present surface-water and ground-water supply fully developed in summer in Walla Walla area. Local overdraft of ground water at College Place near Walla Walla and at Pullman; regional overdraft not indicated.	Detailed studies of ground-water potential and of availability of water from Palouse and Tucannon Rivers and others.	Some additional surface storage and artificial recharge of ground water may be feasible in Walla Walla area. Ground water widely available in southeastern area but little known of potential yield and relation to surface water.
South-central area	Potentially valuable agricultural areas virtually undeveloped because of low precipitation. Future of area dependent upon complete utilization of surface and ground water.	Basic data of all types inadequate for design of power and irrigation projects. Little ground-water information available.	Considerable power production and irrigation probably feasible, if done on basis of good data. Development must be made to conform to requirements of Lower Columbia fish sanctuary. Ground water probably available in Glenwood and Goldendale areas and in Horse Heaven Plateau.
Southwestern area (lower Columbia River basin)	Industrial and irrigation use of water increasing rapidly. Current status as fisheries sanctuary prohibits further large dams. Federal-State program for increased salmon propagation is under way.	Increasing development has created a critical need for data on available water resources, including extent, character, and safe yield of aquifers.	Considerable potential power and irrigation development. Ground water available in Clark County and Jackson Prairie-Cowlitz River area but potential unknown.
Pacific Coast and Puget Sound areas	Area of heavy and increasing water use. Supplemental irrigation increasing. Pollution of lower Chehalis River and small streams near Shelton, Tacoma, and Seattle. Flood problems in much of area; sedimentation of flood-control reservoirs, especially in Nooksack and Skagit River basins. Local overdraft of ground water near Everett.	Detailed ground-water studies to determine safe yields of aquifers and methods of development to prevent salt-water encroachment along the coast and near Puget Sound. Data on flow of small streams for design of headwater reservoirs.	Increased use of ground water and development of reservoirs in headwater areas will be source of most of increased supply. Ground water known or believed to be abundant in much of Puget Basin area. Flood, pollution, and sediment control essential.

West Virginia

Substantial rainfall and runoff but steep slopes and rocks of low average permeability cause rapid runoff and short surface-water supplies in summer and fall unless storage is provided. Except along major streams developments are not large but they are widespread and of critical importance in each area. Serious problem of water quality in coal-mining areas. Large ground-water supplies along valley of Ohio River.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Ground water	Few areas of large use but many of small use totaling about 116 m.g.d. About 70 percent of people get domestic water from wells; Parkersburg is largest city using ground water. Drainage of acid water from coal mines pollutes streams, requiring costly treatment or making ground-water development necessary in places where supplies can be developed only with great care. At Bramwell, such a development was unsuccessful because wells were spaced too closely. Local overdevelopment at Pennsboro. Many mining communities have inadequate supplies of poor quality developed mainly for use at the mines and especially inadequate in dry weather.	Basic data inadequate in all parts of State. Information needed on occurrence of ground water, quality and quantity available in areas of use and for future uses in untapped areas. Except for large supplies along Ohio River, requiring comprehensive studies such as that made at West Virginia Ordnance Works at Pt. Pleasant, most of supplies to be developed are small and adequate data can be obtained through modest studies.	Small to moderate ground-water supplies (7,000-80,000 g.p.d.) available in main part of State. In area of Permian rocks in northwest, wells seldom yield more than 20,000 g.p.d. In areas of folded rocks in east, limestones yield 100,000-600,000 g.p.d. to deep wells and supply all large springs. Largest supplies available in alluvium of Ohio Valley - almost unlimited supplies by induced infiltration where alluvium is thick and permeable. Smaller supplies in Kanawha, Little Kanawha, and Monongahela Valleys and possibly from thin alluvium in tributaries of Potomac. Wheeling considering ground water to replace polluted water from Ohio River. Surface water probably necessary at Pennsboro.
Surface-water supply	About 175 communities, including all large ones except Parkersburg, use surface water for public and industrial use. Major centers along Monongahela River below Clarksburg, Kanawha River below Kanawha Falls, and Ohio River. Shortage of water from polluted West Fork River for Clarksburg and from Elk River at Charleston. Other towns with occasional shortages are Glenville, Milton, Richwood, Weston, and reportedly West Liberty and Bethany. Similar industrial shortage in dry years, especially at Charleston.	Data on flow of streams to determine necessity for and to permit economical design of reservoirs. A recent request for data on quantity and duration of flow at 34 localities could be answered definitely for only 7 and by rough estimate at others. Quality-of-water studies needed.	Storage on tributary streams to provide ample water in dry season, and flood and pollution control as well. Tygart Dam on Tygart River near Grafton is good example. Probable large future synthetic-fuel development will require great quantities of water and make storage imperative.
Stream pollution	Pollution by acid mine waters serious problem, especially at times of low flow; West Fork and Monongahela Basins particularly affected. Strip-mining operations will lead to future sedimentation problems. Ohio River badly polluted.	Data on quality of water to determine degree of pollution and methods of control.	State actively engaged in control of sewage and industrial pollution, except that from mine drainage, so far exempt by law. Ohio River problem under attack in cooperation with other States in basin. Additional storage needed for dilution in time of low flow.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Floods	Flash floods in spring common on unregulated streams.	Stream-flow data for reservoir design.	Federal flood-control dams on Tygart River near Grafton and Bluestone River at Hinton, and West Penn Co. dam on Cheat River at Lake Lynn, Pa., provide considerable protection in their basins, also greater low flow for water supply and dilution of polluting material. Dam under construction on Elk River at Sutton. Navigation dams on Ohio River provide no flood protection. Additional dams on tributaries not now regulated are needed.

Wisconsin

Average precipitation about 30 inches; no noticeable decrease since 1837. Runoff about 10 inches; distribution in year about same as in past. Stream flow fairly well sustained because of blanket of glacial drift and many lakes that act as regulating reservoirs. Some minor flood problems. Some problems of pollution of streams and lakes by industrial and municipal wastes. Large over-all water supply and relatively few serious problems. Large ground-water supplies in glacial valleys and plains in all but southwestern part of State, and in sandstones in southern, western, and eastern parts. About 280 m.g.d. of water used for public supply; other uses not known.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Surface water for public and industrial supply	Surface water used for 26 of larger cities; about 145 m.g.d. supplied. Most industries in these cities use water from public supply, except in Milwaukee area where many wells are used. Considerable power development, especially on Wiscoinsn River, one of most completely developed streams in country.	Additional stream-flow data for reservoir control; analysis in conjunction with observation-well records to predict stream flow, as by Wisconsin Valley Improvement Company. Records on small streams to guide increasing development, especially irrigation.	Large additional development possible.
Irrigation	Increasing rapidly; now being done in at least 35 of 71 counties; about 12,000 acres irrigated in 1948 with 3,600 acre-feet of surface water and 1,400 acre-feet of ground water.	Stream-flow data as above. Ground-water studies to locate and evaluate areas of possible irrigation, which are incompletely known.	Large additional development possible. Ground-water use likely to increase faster than surface-water, especially in central sand-plain area. Integrated development needed in sand-plain area, as ground water supplies all stream flow except that of Wisconsin River itself and much of that in dry weather.
Ground water	Ground water used by 385 of 411 municipal supplies (about 135 m.g.d.) and almost all rural uses. Most industries use public supplies but some have their own wells, particularly Milwaukee and Green Bay areas.	Ground-water studies on small scale so far. Substantial increase needed to evaluate supplies in both developed and undeveloped areas.	Greatly increased use possible in most of State, even in vicinity of heavily pumped areas if wells are spaced properly. Especially promising sources are glacial valleys and plains, and sandstones in middle part of State in and near recharge area. Glacial valleys are poorly known; they include valleys of Wisconsin and Rock Rivers and a valley extending through Lake Puckaway and Green Lake in Green Lake and adjacent counties. Bedrock in northern part of State poorly productive and glacial aquifers more scattered than elsewhere; surface water relatively abundant.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Milwaukee-Waukesha area	About 20 m.g.d. pumped from artesian sandstones in Milwaukee County plus some in eastern Waukesha County. Water levels have dropped continuously at least since 1877, maximum known lowering 370 feet. Lowering in shallow aquifers also where wells tap both shallow and deep, and some local overpumping of shallow aquifers where domestic wells are numerous.	Studies under way; continuation needed to provide estimates of yield under various conditions of pumping.	Problem largely economic—a matter of pumping lift—so far, as aquifers have not been unwatered. Problem similar to that in other artesian areas distant from area of recharge (Chicago area, Dakota sandstone) where withdrawal is largely or entirely from storage so far.
Green Bay area	Pumpage about 10 m.g.d. for public supply and all other uses except irrigation, and cooling and washing with surface water at paper mills. Water levels have dropped maximum of about 400 feet since 1886. Decline also occurring above Green Bay in Fox River Valley beyond DePere.	Studies under way; continuation needed to provide estimates of yield under various conditions of pumping.	As above. Additional ground water available west of area of heavy pumping. Surface water available from Fox River and Green Bay but polluted. Surface water from unpolluted part of Lake Michigan available to east across peninsula by means of pipe line 25 to 30 miles long.
Fond du Lac	Difficulty in obtaining adequate ground water for public supply because sandstone is thin and low in permeability.	Ground-water studies under way. Gaging stations needed to determine availability of water from streams.	Test wells being drilled in areas indicated by studies. Lake Winnebago available but water of poor quality.
Marshfield-Niellsville area	Difficulty in getting adequate public supply from thin glacial deposits above impervious bedrock.	As above.	Ground-water possibilities not exhausted though not highly promising. Surface water probably available but data needed.
Artesian area away from centers of heavy pumping	Water levels have declined because of discharge from flowing and pumped wells and most have stopped flowing. No serious problems yet, but great lowering of water levels will occur in areas that are heavily pumped in future, especially in southeast as distance from recharge area increases.	General studies, detailed studies in areas of use.	

Wyoming

Substantial precipitation on and runoff from mountainous areas. Practically all water originates within State and much of it must be allowed to flow out for downstream uses under existing decrees. Shortage of water, lack of irrigable land, or high altitude and cold climate in areas of good soil limit irrigation development. Green River basin is only major basin where water supply is believed to exceed need under conditions of full development. Ground water available in alluvium of principal streams; Tertiary rocks in northeastern, southeastern, southwestern, and west-central and northwest-central areas; and pre-Tertiary artesian strata in a few narrow belts. Serious problems of erosion and reservoir sedimentation and quality of water. Basic data deficient on small streams, ground water, and quality of water. Some studies being made in cooperation with State and under Missouri Basin program.

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
North Platte River basin	Area of largest water use, principally for irrigation. Further development limited by court decrees. Serious sediment and water-quality problems. Ground water used for irrigation and other purposes in Goshen County and adjacent Scotts Bluff and Morrill Counties, Nebr., Glendo area, Pumpkin Creek area, Horse-Bear Creek area, Laramie area, and northern Platte County.	Greatly increased ground-water studies to evaluate aquifers. Some general studies made in Goshen County and in Laramie, Wheatland Flats, and Glendo areas.	Reservoirs on the two principal streams provide flood protection. Considerable ground-water development possible in areas named in first column, especially Goshen County, and in Wheatland Flats area, in Sweetwater Valley, and in Laramie, Carbon, and Platte Counties. Interference with surface water should be considered. Salvage of waste and drainage would be useful effects of development in parts of Goshen County and in Wheatland Flats area.
South Platte River basin	Only small part of basin lies in Wyoming. Ground water used for part of public supply at Cheyenne. Used for public supply and especially for irrigation in Egbert-Pine Bluffs-Carpenter area (13,500 acre-feet in 1947).	Safe yield of Egbert-Pine Bluffs-Carpenter area.	Some additional ground-water development feasible outside present areas of pumping.
Powder, Belle Fourche, Cheyenne, and Tongue River basins	Considered area of most deficient water supply in State under present conditions. Alternating floods and deficient low flow in streams. Serious sedimentation problems. Ground water used for domestic, stock, and limited railroad and industrial use.	Careful inventory of ground water in entire area to determine availability for possible large future developments.	Additional surface storage to prevent floods and provide increased low flow. Soil-conservation and other sediment-control measures. Ground-water supplies appear to be generally small but should be carefully studied because synthetic-fuel industry may develop. Alluvium offers promise for large dry-season supply if recharged naturally or artificially from stream flow in time of flood.
Big Horn River basin (including Wind River basin)	Basin is area of heavy water use. Extensive irrigation along Wind and Big Horn Rivers and tributaries. Flash floods on tributaries and ice-jam floods on Big Horn River. Serious problems of sedimentation, and of changes in quality resulting from irrigation. Existing or potential waterlogging in many areas.	Detailed sediment, quality, ground-water, and stream-flow studies to permit more adequate planning of basin development.	Careful development of basin to provide maximum water and minimize floods, low-flow shortage, sedimentation, and water-logging. Ground water available in alluvium of main streams, in small quantities and of poor quality in Tertiary rocks in most of basin, and in artesian strata [illegible]

Area or subject	Current situation	Deficiencies in information	Corrective measures and further development
Green River basin	Irrigable area about 500,000 acres; about half receiving water, chiefly for hay. Little use of ground water, chiefly municipal, stock, and domestic.	General studies to outline ground-water potential. Sediment, quality, and flow data on small streams.	Apparently more surface water available than needed for irrigable area. Large ground-water supply in alluvial fan at west side of Wind River Mountains; essentially undeveloped so far but contributes to flow of Green River. Only small supplies available in bedrock in most of basin.
Snake River basin	No serious problems yet.	General surface-water and ground-water studies to outline future possibilities, especially in regard to division of water with downstream users.	Large surface supply available; also ground water in alluvium along streams. Considerable additional development feasible.
Bear River basin	Interstate stream. About 750,000 acre-feet per year wastes to Great Salt Lake in Utah. Distribution of water among Wyoming, Idaho, and Utah disputed.	Comprehensive hydrologic study of basin in all three States.	Integrated development under compact to reduce waste and provide maximum utilization and equitable distribution of water.