UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Washington 25, D. C.

GROUND-WATER PROBLEMS IN THE UNITED STATES

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Chief Hydraulic Engineer

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Chief Hydraulic Engineer
U. S. Geological Survey

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Introduction

It gives me a great deal of pleasure to be here today and discuss with you the ground-water situation in the United States, as viewed by the Geological Survey. Many of you are aware of our responsibility in this regard, for the Survey has ground-water investigations under way in most of your States in cooperation with State and municipal agencies. However, it always helps to review the situation, summarize our problems, and restate the goals toward which we strive.

In recent years, as a result of a phenomenal increase in the use of water in cities, on farms, and by industries, there is a growing awareness of the vital part that water resources play in our complex national economy. The basic need for water may be compared with that for air and food. Wherever the supply of fresh water has been scarce or lacking, as in arid and semiarid regions, the significance of water as a limiting factor in the utilization of other resources and in the progress of our modern civilization has been keenly appreciated. Fortunately, in large parts of the country the supplies of fresh water are plentiful. However, in many localities the development of our economy has created water demands of a magnitude and variety that have exceeded all previous expectations. Consequently, supplies which until recently have been considered essentially inexhaustible are now recognized to have limits, which, either immediately or prospectively, fix the extent of economic development.

Lack of water has played an essential part in the development and decline of civilizations since the beginning of recorded history. Generally, this has been done in the quiet, subtle manner of restricting growth; but, at least in certain cases, the fall of civilizations may be attributed to droughts, floods, or changing water tables. In some parts of our own country today, industrial and agricultural development has nearly reached a maximum as water supplies have become fully developed. Indeed, in a few places, irrigation eventually may have to cease or be seriously curtailed and industries may have to move as Mother Nature forces a decrease in overdeveloped water supplies. Such problems are an impelling reason for accelerating the inventory and appraisal of our water resources.

Function of Geological Survey

The United States Geological Survey has been active in the investigation of our water resources since 1888, and appropriations have been made annually by Congress since 1895 for basic studies of the occurrence, availability, and quality of both surface and ground water. Recent appropriation acts have defined the water-investigational activities as "gaging the streams," "determining the water supply of the United States," and "investigating methods of utilizing the water resources."

Cooperation with States has been in effect practically since the beginning of the investigations, having been arranged first with the States of Kansas and Nebraska in 1895. Although Congress had been informed annually that such cooperation with States was in progress and by law had authorized the use of such funds on a cooperative basis, it first specifically recognized the cooperation in the annual appropriation act for 1929, extended the cooperation to municipalities and State political subdivisions on the same basis of participation as was indicated for States, and provided that the Federal participation should not exceed half the cost of any investigation. Now, cooperation is in effect with all the States, with the Territory of Hawaii, with Puerto Rico, and with several municipalities and State political subdivisions. Cooperation with municipalities and other State political subdivisions is, however, small in comparison to the cooperation with States.

Several Federal agencies, notably the Corps of Engineers, the Bureau of Reclamation, the Department of State, the Tennessee Valley Authority, and the Atomic Energy Commission contribute funds in substantial amounts to the Geological Survey for water investigations that are needed in connection with their activities.

The aggregate of all funds for 1949 was about 8½ million dollars, and the approximate division among the three sources was about 3½ million by direct Congressional appropriation to the Survey, which was largely restricted to use in cooperation with States and municipalities, 2½ million by cooperative allotments by States and municipalities, and 2½ million by transfer from other Federal agencies for specific investigations needed by those agencies and not adequately provided for by regular Survey or State cooperative funds. Thus, the funds for the Survey's water investigations come from many sources, with the result that finances are somewhat complex and involved, and do not provide adequately for general investigations.

Because the major part of the funds is dependent on cooperation with States and on transfers by other Federal agencies, the programs are not always distributed to serve best all needs for information. In other words, a comprehensive countrywide plan has not been possible thus far, and no systematic plan has been or could have been followed consistently through the years under the methods of financing that have prevailed.

However, cooperation with States and Federal agencies insures that the investigations will be made so as to meet real needs and to serve worthwhile uses. Such cooperation on a Nation-wide basis is fundamentally sound because the States and other Federal agencies share in responsibility for a great fact-finding activity that is mutually advantageous. Through this cooperation the highest standards of technique and accomplishment on a Nation-wide basis are assured.

The Geological Survey now operates more than 6,000 stream-flow and stage stations throughout the country and is making ground-water investigations in practically every State and territory of the Nation. Water-level measurements are made periodically in about 15,000 wells. Quality-of-water and sediment studies and special hydrologic investigations are being carried on in many places throughout the country. Hydrologic research activities and equipment-development programs are also being advanced as rapidly as funds and availability of personnel will permit. Water-temperature records are being collected at many of our stream-gaging stations and in observation wells because of the growing demand for such information on the part of industry and the fish and wildlife interests.

Because water is a mobile and renewable resource, its investigation involves studies of movement, recharge and discharge, and changes in quality, in addition to the general problems connected with the investigation of other natural resources. Surface water percolates into the ground, becoming ground water; ground water reaches the surface in springs or seeps and becomes surface water; man-made changes such as lowering ground-water levels through pumping may induce or increase infiltration and thus reduce the normal low-water flow of streams. As sea water may penetrate far upstream in coastal streams during periods of low flow, so may overpumping of ground water from aquifers near the coast allow saline water to move underground toward centers of pumping, with resulting danger of destroying the fresh ground-water supply. Thus, as an important part of evaluating the water resources, the Geological Survey has the primary responsibility of investigating the occurrence, movement, recharge, and discharge of ground water, the interrelation between surface water and ground water, effective utilization of both ground and surface waters to secure maximum benefits, the optimum distribution of wells, and many other problems which require intensive research.

Use of Ground Water

As I have already stated, the use of water during the past century in the United States has increased by leaps and bounds. In 1850 only a few water-supply systems were in operation in the United States and only a few homes were connected with the city mains. In 1945 there were nearly 16,000 public supplies, including about 12,000 served from ground-water sources, and nearly every urban home was served with city water. The per-capita consumption of water also increased tremendously through the use of sanitary facilities, street cleaning, fire protection, and a multitude of industrial uses. Moreover, thousands of private industries have their own wells or surface reservoirs. In 1940, 20 million out of 57 million people in the rural areas of the country were supplied with running water.

Demands for irrigation, hydroelectric power, and other uses have expanded rapidly. In the West and Southwest, irrigation demands were insignificant in 1850, but in 1939 about 21 million acres of land were irrigated from Louisiana to California and from Texas to Idaho and Washington. Millions of additional acres have been brought under irrigation since then. In the East and Southeast, the practice of irrigating crops during drought periods has been found to increase the average yield per acre more than enough to justify the cost, and the practice is growing rapidly.

The earlier developments of water supplies were made largely from surface-water sources. The development of ground water lagged for a variety of reasons, and at the beginning of the 20th century there were only a few areas in this country in which large quantities of water were withdrawn from wells. Since that time, however, the improvement of well-construction methods, the introduction of cheap power and superior pumping equipment, and certain advantages which ground water provides have combined to increase the use of ground water in nearly all parts of the United States. Furthermore, in much of the arid West, the normal flow of most streams has been fully appropriated, and ground-water development is the only remaining practical means of increasing the supply.

In recent years, added to these causes of increased use of ground water have been the last war and its demands for quickly developed large supplies of pure water and, since the war, the inflation and high prices of farm and industrial products, with the corresponding increases in products, with the corresponding increases in production and demands for more water.

Since 1935, the pumping of water from wells in the United States has increased from about 10 billion to more than 20 billion gallons daily. Figures 1 and 2 show, respectively, the total use of ground water in the United States in 1945, and the use of ground water in metropolitan areas in 1945.

The average amount used for various purposes during 1945 has been estimated as follows:

	Billion gallons daily
Irrigation	10
Industrial (excluding water from municipal supplies)	5
Municipal	3
Rural (excluding irrigation)	2

Except for a total of a little less than a billion gallons a day used in the States of Arkansas, Louisiana, and Florida, and small amounts in a few other Central and Eastern States, all the 10 billion gallons a day for irrigation was used in the 17 Western States. California used about half the total, or about 5 billion gallons a day, and Arizona and Texas were second and third, respectively.

Irrigation with ground water in other Western States is increasing by leaps and bounds, however. The use of ground water is an integral part of the plans of the various State and Federal agencies to develop the water resources sufficiently to meet the growing demands. A project in southern Idaho, for instance, is proposed wherein about 600 second-feet, or about 400 million gallons a day, will be obtained from wells during the growing season. The use of this water in relation to existing uses of water in the region must be studied.

The use of 5 billion gallons a day of ground water by industries, not including that taken from municipal supplies, indicates a proportional increase even greater than that for irrigation. Where individual demands are small to moderate, industries prefer ground water especially because of its availability, its freedom from bacterial and suspended matter, its uniform chemical composition, and its uniform temperature, which in the summer is lower than that of surface water and makes the ground water especially useful for cooling.

During 1945 the total withdrawal of ground water by industries in or near 20 typical major industrial cities was 750 million gallons a day. The industries using the most water, in order of amount of use, were oil refining, paper manufacturing, metal working, chemical manufacturing, office and other buildings (including air conditioning and refrigeration), distilling, ice making and cold storage, food processing, rubber manufacturing, meat packing, brewing, railroads, gas and electricity, and dairying. Other uses included rope mills, tobacco processing, shipyards, laundering, ordnance plants, soap manufacturing, aircraft plants, and manufacturing of resinous products. Surprisingly enough, the use for air conditioning, though wide-spread and increasing, is not nearly the greatest industrial use.

Availability of Ground Water

The amount of ground water available in any one place is dependent upon many factors, all related in one way or another to the climate, geology, and topography. The United States can be divided into four major regions with respect to ground water, in each of which the water generally occurs in particular types of underground formations and under different conditions. The four divisions are the East-Central region, the Atlantic and Gulf Coastal Plains, the Great Plains, and the Western Mountain region. Available space does not permit the description of the occurrence of water in these regions, but most of you are doubtless familiar with the general type of geologic formations occurring there. You probably know of the shales, limestones, sandstones, and igneous and metamorphic rocks in the east-central part of the country and the glacial deposits that overlie these rocks in the northern part. You are familiar also with the thick sands and clays and the cavernous limestones of the coastal plains, the widespread outwash sand and gravel deposits of the Great Plains, the alluvial valleys in the West, and the extensive lava beds in the Northwest. If you are interested in more details, I believe you will find some of the Survey's reports on the occurrence of ground water in the United States enlightening and interesting.

Despite the fact that large supplies of ground water are available from the deposits mentioned, many ground-water formations or reservoirs have been overdeveloped locally (and in a few cases over wide areas) to the extent that serious problems have resulted. In some places the supplies are actually limited to a fixed amount, and additional supplies cannot be obtained within the present economic limits. In other places, however, additional water is available and the problem is simply to obtain it in the best and cheapest way. Naturally, as the cost of the water is increased, the people who are paying the bills are beginning to sit up and take notice, and in some cases are beginning to cry "water shortage." However, it must be realized that ground water cannot be obtained without some decline in water levels to cause the water to flow toward the wells, and a decline always means, of course, an increase in pumping lift. It is in the places where the pumping is so great that the water levels will not stop declining before reaching excessive depths, or where the water levels cannot possibly stop declining with the existing pumping rates, or where development of ground water adversely affects surface-water rights on streams to which it is tributary, that the really serious problems occur.

There is a widespread public impression that the over-all ground-water supply of the United States is being depleted at an alarming rate, and that soon the supply may be exhausted. The truth is that there is no such thing as an over-all Nation-wide depletion of ground water, although there are many local areas and a few larger regions where ground-water levels are declining so much as a result of heavy pumping that (at least under existing conditions) they might be regarded as overdeveloped. Nevertheless, large undeveloped supplies remain in many areas—indeed, the present total ground-water withdrawal in the United States represents only a fraction of the potential. Outside the relatively widely spaced areas of overdevelopment there is at present no progressive depletion of ground water. The ground-water level rises in wet years and falls in dry years, and occasionally there is a more or less permanent local decline as a result of land drainage or some similar practice, but on the whole it is safe to say that ground-water reserves in the United States are sufficient for greatly increased use of this resource. Instead of being faced with the national problem of reducing our ground-water use, the problem is, rather, one of distributing the use so that overdevelopment of local areas can be eliminated or kept to a minimum, and so that better advantage can be taken of the ground water that is now wasted through passing unused on its way to streams and thence to the sea.

Methods of Increasing Ground-Water Supplies

In recent years considerable attention has been given to methods of artificially increasing ground-water supplies in those areas where there are definite indications of overdevelopment - or where natural supplies are too small to permit expanded development. Other than the obvious course of importation of water, the most favorable methods are induced infiltration from streams, artificial recharge, and destruction of wasteful water-loving plants called phreatophytes.

As more and more has been learned about ground-water hydrology, and as methods for constructing larger and more efficient wells have been developed, it has been realized that, where geological conditions are favorable, large supplies of clear, cool water can be obtained by locating large wells adjacent to streams and drawing the water from the streams through their beds and through the sand and gravel of the ground-water formation into the wells (see fig. 3). Thus, the water is filtered naturally and advantage is taken of the cooling effect of the ground during the summer; or, where aquifers are partially depleted by heavy summer pumping, they may be replenished by recharge during the winter with cold surface water. Ever since large ground-water supplies have been developed near streams, some water has been induced into the ground-water reservoirs from the streams, but only recently have large-scale developments been made with this primarily in mind. During the recent war a number of such installations furnished water to ordnance plants along the Ohio River and other streams of that general area. At Charlestown, Ind., for instance, a continuous supply of more than 40 million gallons a day was obtained from seven collector wells, and the primary source of the water was the river less than 200 feet away. The water was reported to be perfectly clear and free of bacteria, and its maximum temperature in the summer and fall was more than 15 degrees less than the maximum temperature of the river water.

Artificial recharge of ground-water reservoirs has been practiced for many years in the United States, but on a comparatively small scale except in California. However, recently the overdevelopment of some of our underground reservoirs has brought it to the fore as a means of obtaining very large additional supplies. Artificial recharge is accomplished by spreading surface water on the land and allowing it to percolate down to the water table, or by pouring it into the ground through wells -- or it may be accomplished with ground water that has been used and is returned to the ground. Generally, the problem is to store water for future use or to take advantage of the ground's natural filtering and cooling effects to make the water more suitable for use.

The most widespread use of artificial recharge by spreading over the land is in California, where flood waters of many mountain streams are spread over the permeable alluvial gravels alongside the streams for storage and for use later when the streams are not flowing and extensive irrigation and municipal demands must be met from wells.

The greatest use of artificial recharge through wells is on Long Island, N. Y., where the State Water Power and Control Commission requires that water used for cooling from wells with a capacity of more than 100,000 gallons a day be returned to the ground through artificial-recharge wells. At times more than 60 million gallons a day has been returned through more than 200 recharge wells and several pits during the summer.

Figure 4 is a generalized section through a part of Long Island, showing conditions before recharge. The heavy pumping from the well shown had lowered the water table so much that sea water was moving in toward the well and contaminating the fresh ground-water supply. Figure 5 shows the effects of putting the pumped water back into the ground between the pumped well and the coast. The water level was raised and the sea water kept out of the fresh-water formation. Also, part of the recharge water was available for repumping.

The third principal means of increasing supplies, which is receiving much attention, is by control of the consumption of water by phreatophytes -- plants that habitually grow where they can send their roots down to the water table and, through the process of transpiration, discharge relatively large quantities of water into the air. In general, the large amount of ground water so discharged has little or no beneficial use. In fact, of the common phreatophytes, only one -- alfalfa -- has a highly beneficial use.

It is estimated that something like 15 million acres of land in the western part of the United States produce relatively worthless vegetation at a loss of something like 20 to 25 million acre-feet of water per year which conceivably might be put to more beneficial use. Much of this water could be salvaged by lowering the water table or by otherwise destroying the phreatophytes. Figure 6 is a graphic representation showing rough estimates of the use by phreatophytes of water badly needed for irrigation in Nevada and Arizona.

In numerous places the water table has been lowered by pumping, which incidentally has destroyed some of the phreatophytes and has salvaged the water they were wasting, but no large-scale development has yet been made with that as the primary purpose. However, in the future it is expected that not only will the water table in some areas be lowered for that purpose, but that other means will be employed to destroy the useless vegetation so that the water it consumes may be diverted to more worthwhile purposes.

Problems of Overdevelopment

By discussing methods of increasing ground-water supplies, and the tremendous reserves that remain undeveloped in some areas, I am attempting to instill a note of optimism into a picture that is being made cloudy and depressing by rumors and exaggerated fears. We are not running out of ground water, and, on the whole, we never will run out. However, this optimism must not minimize the seriousness of the local problems that have been created through lack of knowledge of our ground-water supplies and consequent overdevelopment. Though only a few of these problems will prove to be impossible to solve by one or more means of conservation or by artificially increasing the supply, the solutions in general will be costly and time consuming. Some of the problems might be described.

As an example, the Coastal Plain in Los Angeles and Orange Counties, Calif., where water is pumped from alluvial sand and gravel, is one of the most heavily developed ground-water areas in the United States, and parts of it are seriously overdeveloped. One of these is the so-called West Basin southwest of Los Angeles. There the current withdrawal of ground water is roughly twice the estimated fresh-water recharge. Part of the excess of withdrawal over fresh-water recharge is coming from storage, with declining water levels, and perhaps a quarter of the fresh water pumped is being replaced by salt water that is moving eastward within the aquifers from their undersea extensions. Already some wells as much as 2 miles inland have been salted. To illustrate the complexity of the problem, it may be pointed out that the problem cannot be solved merely through reducing the pumpage by half. A large part of the fresh-water recharge occurs by underflow from the main coastal plain to the northeast, through a partial barrier formed by the Newport-Inglewood fault zone, and it occurs only because the ground-water levels in the West Basin are lower than those in the main coastal plain, so that an adequate head is maintained across the barrier. Reducing the pumpage would cause the water levels to rise and so reduce or stop the encroachment of salt water from the west, but the same rise would reduce the hydraulic head across the Newport-Inglewood barrier and thus would cut down the amount of fresh water moving into the West Basin. The solution of the problem doubtless will require keeping the water levels depressed by pumping in the eastern part of the basin, to induce continued underflow through the barrier, and artificial recharge near the coast to raise the water levels to hold back the salt water. The artificial recharge will be difficult to accomplish, because near the coast the water-bearing sand and gravel is covered by deposits of silt and clay, so that recharge wells or pits will be needed instead of simple structures to spread the water over the surface. Add to the physical problems the legal, administrative, and financial problems involved in carrying out the necessary procedure, and it becomes apparent that substantial difficulties are involved. Also, unless additional water is imported from outside the area, even the best solution will permit the perennial development of only half as much water as is now pumped--even less if ground-water levels continue to decline in the main coastal plain.

Ground-water problems of the most serious kind exist in parts of the State of Arizona, where the economy depends largely on irrigation farming. At present about three-quarters of the water used for irrigation is pumped from wells penetrating alluvial deposits of sand and gravel, and areas such as the Santa Cruz and Salt River Valleys are seriously overdeveloped. For the irrigated areas in the southern part of the State as a whole, though accurate figures are not yet available, it is estimated that the current withdrawal of more than 2½ million acre-feet per year is considerably greater than the average replenishment. Declining water levels in large parts of the basins, and an increase in the salt content of the water at their lower ends resulting from inadequate ground-water outflow, are posing a serious threat to the permanence of irrigation agriculture in Arizona, and large expenditures will be necessary to develop sufficient water to meet the deficiency. The State legislature has recently passed a law to control the drilling and use of new irrigation wells, and the Central Arizona project proposed by the Bureau of Reclamation is being considered by Congress. These measures will solve some of the problems, but a number will require additional steps.

Another problem whose solution is still remote is that in part of the High Plains of Texas south of Amarillo, where irrigation from wells has been expanding in recent years at a rate greater than in any other comparable area in the United States. In 1934 about 300 wells irrigated 16,000 acres; in 1948 about 10,000 wells irrigated more than a million acres. The withdrawals come from an enormous amount of water in storage that is replenished at a very low annual rate. At present the stored water is being developed on an unregulated and accelerating scale, and already some of the irrigated areas are threatened by declining water levels. Eventually a decision must be reached as to how long the stored water should be made to last and how it should best be developed. The problem is as much one for economists, statesmen, and philosophers as it is for engineers and geologists. To make the decisions and to devise and enforce the necessary laws will be an exceedingly difficult problem, involving much more than determinations of water supply. The same problem must be faced in other areas where aquifers have a large amount of water in storage but only a low rate of recharge. Hitherto legal concepts on the control of the use of ground water have been based on the assumption that the withdrawal must be held within the perennial safe yield, but the High Plains case shows that under certain conditions it may be necessary to modify this principle.

Of course, problems of ground-water overdevelopment are not peculiar to the western part of the United States alone. As previously mentioned, Long Island, New York, presents a case where ground-water overdevelopment in the East has been remedied to some extent by effective action. Large amounts of water are pumped for industry and public supply from glacial-outwash sand and gravel. The pumpage, which for the Island as a whole has been as much as 300 million gallons a day in some years, is concentrated largely in the western part of the island, particularly in Brooklyn (Kings County) and adjacent Queens County. By 1933, the concentrated pumping in the western part had drawn the water table below sea level in an area of more than 40 square miles, salting some wells and threatening many others. Eventually the area where the water table was below sea level became twice as large. On the basis of hydrologic data obtained largely in cooperative studies by the Geological Survey, however, artificial recharge has been introduced to arrest the decline of the water table and effect recovery. The State Water Power and Control Commission and the City of New York are also encouraging the use of surface water for public supply, where practicable, to permit a reduction of pumping. In the summer of 1947 a pumping station that had been withdrawing about 27 million gallons a day was shut down permanently. The combined effects of the artificial recharge and the recently reduced withdrawal have greatly improved ground-water conditions in western Long Island and there is now assurance of a dependable future supply.

At Miami, Fla., hundreds of private wells and two municipal well fields had been lost to salt-water encroachment, and a third well field 8 miles from the seashore was going salty when the Survey was requested in 1939 to ascertain the causes of the trouble and determine the facts pertaining to water available for public supply. Studies of the geology and hydrology revealed that the water-bearing formations below 300 feet contain only saline artesian water, but the shallower formations include fresh water in one of the most permeable aquifers ever investigated. This aquifer underlies all the Miami area and extends westward under the Everglades. It is wedge-shaped, ranging from 125 to 300 feet thick at Biscayne Bay and thinning to a feather edge 40 to 50 miles west near the margin of the Big Cypress Swamp. It is recharged by rainfall mounting to about 60 inches a year, and formerly would have supported very large developments of fresh water. However, the upper part of the aquifer is now cut by canals dug to drain the Everglades, and by 1939 the drainage operations had lowered the available fresh-water head so that the equilibrium between salt and fresh water had been disrupted to such an extent that major salt-water encroachment had been caused. The Survey's findings showed, however, that resotration of the fresh-water table to a height of 3 feet above sea level would stop the encroachment.

On the basis of these findings, engineers of the City of Miami and Dade County designed and placed low adjustable and removable dams in the seaward ends of the tidal canals. These raised the water table and closed the canals to sea water, with the result that salt-water encroachment has been largely stopped. In addition, new well-field sites are now being developed in areas that will be perennially safe, and lawmakers have the basic data necessary to enact legislation for the future protection of the local water resources.

Need for Basic Data and Application of Scientific Methods

The foregoing examples, though outstanding, are similar to a number of other cases of overdevelopment. Most of the problems, however, can be prevented or solved by proper application of scientific ground-water knowledge and methods. Such problems occur in formations where the perennial supplies that can be developed are greater than the present withdrawals, but where the wells are not properly constructed or located, and where the withdrawals are not made in an orderly and efficient manner. It has been the experience of the Geological Survey, when it is called in to help solve the problems, that this condition is the one most often encountered. Actually the problems are serious, and it often costs many thousands and even millions of dollars to correct them, but they can be solved and could have been largely forestalled by proper investigation and development in the beginning.

Take the case of Louisville, Ky., for example. In 1943 the pumpage from wells for war industries reached a peak of about 75 million gallons a day. Before the war it was only about 37 million. The water levels in 1943 were dropping so fast that the yields of some wells had decreased to a quarter of their original amount, and in the rubber-manufacturing district there appeared to be less than a 2-year supply left in the ground-water reservoir. All the developments had been made without prior investigation of the ground-water reservoir, its natural recharge, its permeability, and other essential hydrologic and geologic factors. When the Geological Survey was called in to help solve the problem, the reservoir was carefully mapped and the sources and amounts of recharge were determined. It was found that the redharge, under existing conditions of development, was only about 40 million gallons a day. Therefore, it was necessary for the industries to take action in a hurry, and they did it. The use of water was decreased by means of cooling towers, recirculation, and other water-saving measures, and some industries began to buy water from the city, which is supplied with Ohio River water. Others relocated their wells closer to the river in order to draw in additional recharge, and a few artificially recharged the underground reservoir with city water or with ground water that had been used for cooling. By 1945 the pumpage had been decreased to about 45 million gallons a day, and now it is less than 40 million. The problem was solved, but it has been estimated that the cost of the measures taken to prevent a water shortage was around $5,000,000. The irony of the situation is this -- the Geological Survey's investigations, begun during the war and continued since then, have shown conclusively that several hundred million gallons a day of cool ground water can be obtained by locating wells along the Ohio River to the north and south of the city, where the water can be made to infiltrate from the river at high rates. A large part of the $5,000,000 probably could have been saved had the proper investigations been made in advance to show just how much water could be obtained from the ground under various methods of development.

Another very important reason for making ground-water investigations, though little publicized, is to furnish the basis for effecting simple economies in everyday developments. Ground-water hydrology is now just as sound a branch of engineering as structural engineering, and who would think of constructing a $100,000 building without an adequate engineering design? It perhaps could be built safely without the design, but at what cost? Yet, how many ground-water developments do you know that cost $100,000 or more and that were made without complete knowledge of the underground formations or the recharge to them? Little economies in such things as the selection of proper screens, proper pump settings for future conditions, selection of the most desirable aquifer where there is more than one, proper penetration of well, and the most favorable well spacing can add up very quickly to far more than the cost of the necessary investigation.

A major part of the job before us, therefore, is to find out what the conditions are before developments are installed, and to insure against failures due to local overdevelopment to permit the most efficient and economical development.

Although during the last 50 years the Geological Survey has obtained a substantial amount of ground-water data for thousands of localities, by far the greater part of the country has not yet been adequately investigated. Figure 7 is a map of the United States showing areas for which substantial or comprehensive ground-water data have been obtained. Some general knowledge is available for the other part, to be sure, but extensive field investigations are generally needed before major ground-water developments can be made with assurance of safety and economy. In view of the foreseeable needs for larger and larger supplies of ground water, therefore, it is vitally important that all the available supplies be mapped and the quantity and quality of the water be determined before large-scale installations are made. Furthermore, once the installations are made, it is important that continuing observations be made so that accurate inventories of the supplies can be maintained, thus permitting any necessary adjustments in rates of withdrawal to be made in an orderly and efficient manner before disaster strikes. Only by such a procedure of prior investigation and continuing observation can our ground-water supplies be properly utilized and conserved, thus taking their proper place in the sound development of the Nation.

A few examples might be given of the type of information resulting from such investigations. Figure 8 is a map of the vicinity of Dayton, Ohio, showing present valleys in the rolling glacial-drift topography and the ancient buried valleys that are filled with preglacial alluvium and glacial drift. Large ground-water supplies can be obtained only from these buried valleys, and this map now makes it possible for prospective ground-water users to drill in the proper places without wasting their efforts in unproductive areas.

Figure 9 is a map of Fayette County, Ky., around Lexington, showing areas where there is about a 90-percent chance of obtaining fresh ground water in the underlying limestone, areas where there is only a 50-percent chance of obtaining water, and areas where there is very little chance of obtaining a usable supply. This map is expected to save thousands of dollars of worthless drilling and to encourage farmers in the more productive areas to seek pure ground-water supplies rather than use cisterns and contaminated ponds.

Figure 10 is a diagrammatic section through a well at Camp Hood, near Killeen, Tex., showing the original water level, the pumping level expected by the camp planners at the time the pump was installed, the pumping level computed by the Geological Survey on the basis of pumping tests, and the actual pumping level. It will be noticed that the pumping level estimated by the planners was considerably in error, whereas that computed by the Survey on the basis of scientific tests was nearly correct. Had the pump been set originally on the basis of scientific tests rather than "guesstimates," the expense of resetting it and replacing certain parts of the assembly with heavier-duty parts would have been avoided. Actually, however, pumps were set too high in seven wells at the camp, and considerable expense was entailed in resetting them. Furthermore, the high pumping costs finally necessitated the development of a surface-water supply and the partial abandonment of the wells. It is probable that a proper investigation in advance would have saved a good part of this waste. As a result of such experiences, resulting from lack of scientific ground-water data, the Army later became extremely data-conscious and in most cases insisted on detailed investigations before proceeding with development.

Legal Aspects

No discussion of ground-water problems would be complete without reference to the legal aspects of ground-water development and utilization. A large proportion of the persons concerned with water supplies now recognize the need for control of large-scale withdrawals of ground water. However, there are wide differences of opinion as to the best methods to achieve maximum utilization of the water and yet protect individual rights and liberties.

Three major rules have been in use with regard to the right to use ground water. The first is the English or common-law rule, according to which any person can withdraw from wells on his land as much water as he pleases, at any time, without regard to the effect on the supplies of others. This rule is satisfactory only so long as relatively small supplies are withdrawn. It is still the rule likely to be followed by the courts in some of the Eastern States.

The second rule is the so-called American rule, or rule of reasonable use, under which a person may withdraw as much ground water as can be put to beneficial use on his own land overlying the ground-water source, having due regard to his neighbor's similar right. Under this rule, waste of water, such as the discharge from uncontrolled flowing wells, can be prohibited. The so-called doctrine of correlative rights, which is a form of the rule of reasonable use, is now followed in California and some other States. It makes clear the mutual interdependence of ground-water users whose land overlies a common supply. If there is not enough water for the reasonable demands of all, this rule theoretically provides for apportionment of the water on the basis of the area of land held by each user (not on the basis of priority of use). So far no such apportionment is known to have been made for a large ground-water area with a common source, but the first steps have been taken for such an apportionment in the West Basin near Los Angeles.

The third major rule is that of prior appropriation. Under this rule as now developed, water is held to be public property, subject to appropriation for beneficial use. In contrast to the riparian doctrine which applies in the common-law and American rules, under the appropriation doctrine the right to the use of water is held not to be inherent in the ownership of the land overlying the ground-water supply, but to be acquired by appropriation for beneficial use.

The principle of prior appropriation has been highly developed in the West and, for surface waters, is now in force to a greater or less extent in all the Western States. It is the only one of the major rules that provides for the protection of early users against latecomers. Its extension to the control of the use of ground waters simply recognizes the fact that ground waters, like surface waters, are limited in quantity and that it is feasible to determine the amounts available and the best methods of development.

It is the general belief of most of those engaged in the study of water resources that the principle of prior appropriation will generally promote, to the greatest extent, the orderly and effective development of the ground-water supplies and will protect the interests of those who have made investments to produce ground-water supplies. The control of ground water is properly a State function and, where interstate problems are involved, control can doubtless be best accomplished by interstate commissions.

It should be emphasized, however, that successful legal control of ground-water withdrawals requires laws based upon the principles of ground-water hydrology and administered in the light of competent scientific investigation of the area. The successful solution of ground-water problems in Florida, New York, New Mexico, and in other places has been made possible by such hydrologic investigations. Similar investigations throughout the country will provide the basic data necessary for the enactment of sound State laws where required.

Conclusion

In conclusion, I should like to state again that the Geological Survey is optimistic about the future of ground-water development in the United States. Though much investigation remains to be done, we are confident that it will be accomplished and that it not only will help solve our present problems of overdevelopment, but will pave the way for much expansion in the use of ground water. Furthermore, there should no longer be any excuse for haphazard development, serious overdevelopment, and waste of ground water. Proper application of scientific methods of investigation in the future can and will assure successful and economical development of the Nation's abundant supplies.

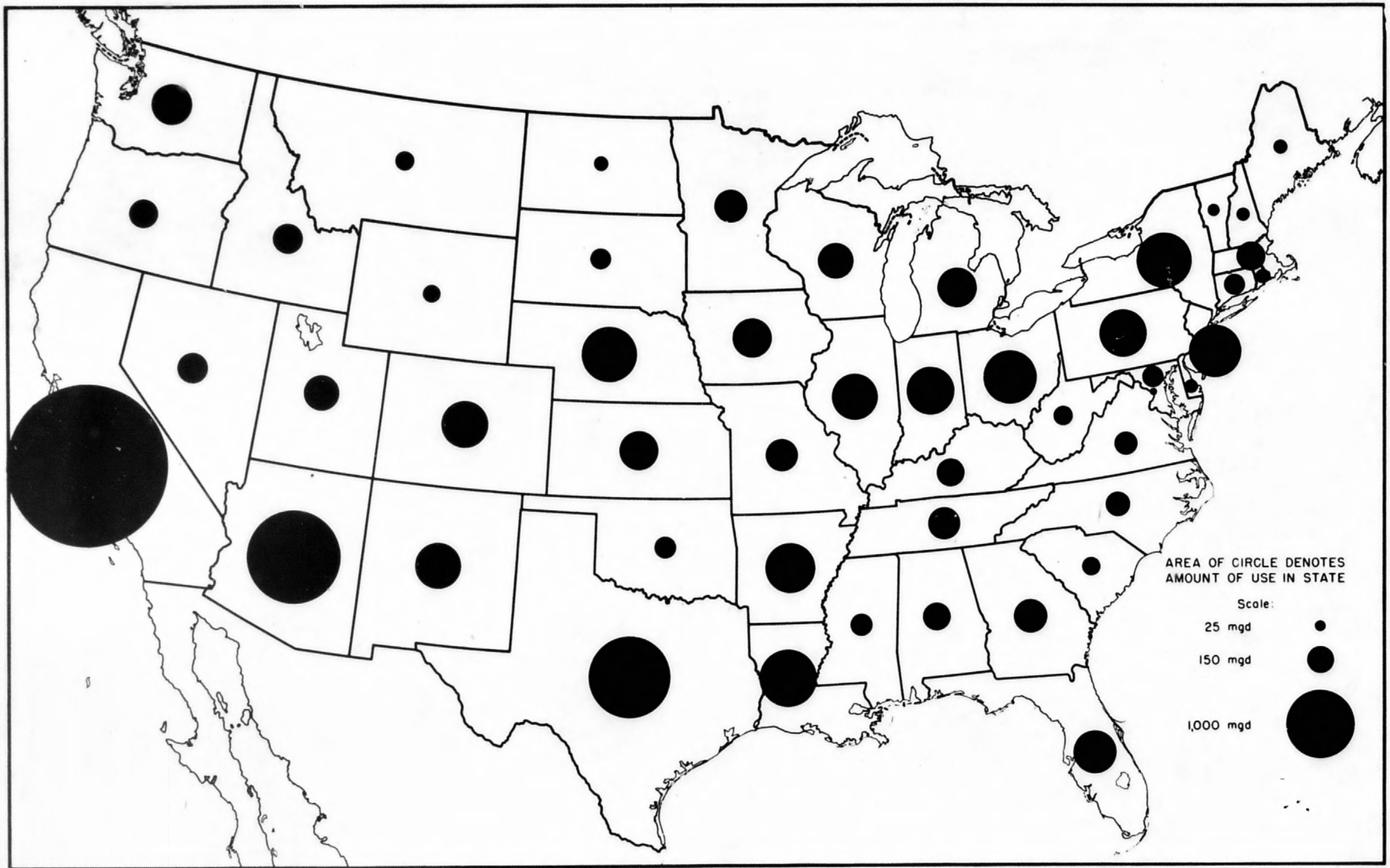

FIGURE 1 — TOTAL USE OF GROUND WATER — 1945

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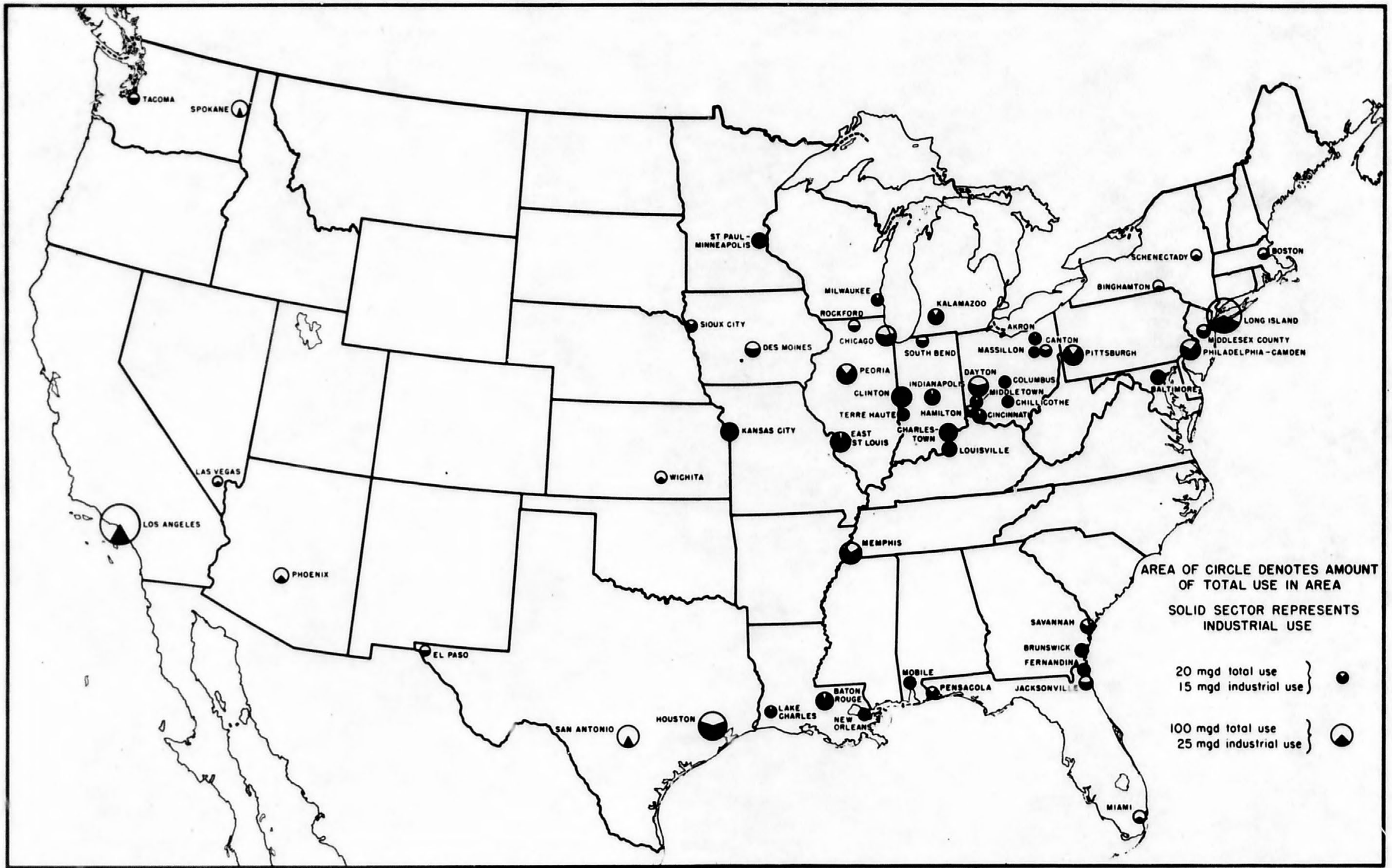

FIGURE 2 – USE OF GROUND WATER IN METROPOLITAN AREAS – 1945
(only areas with 20 mgd or more total use are included)

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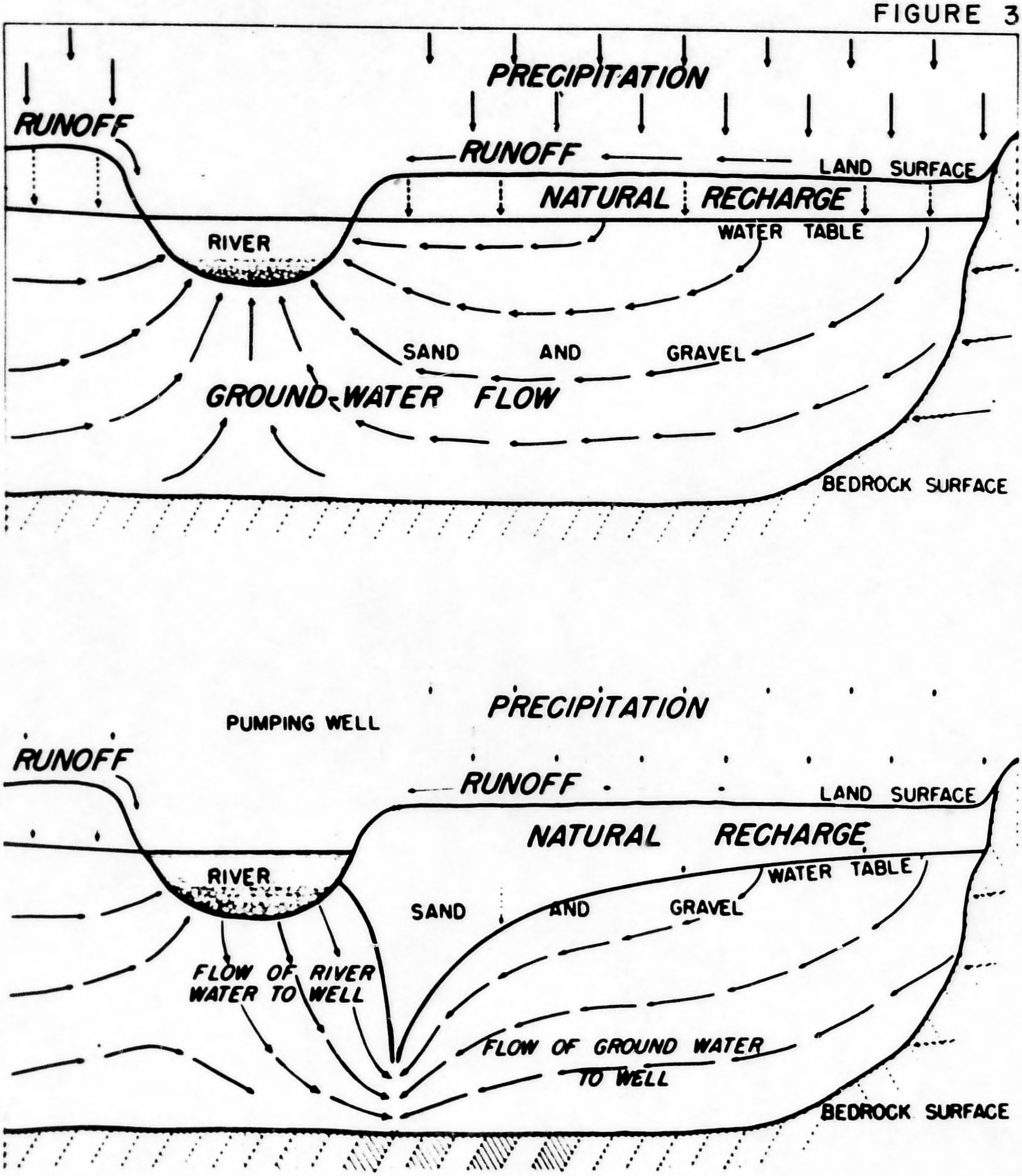
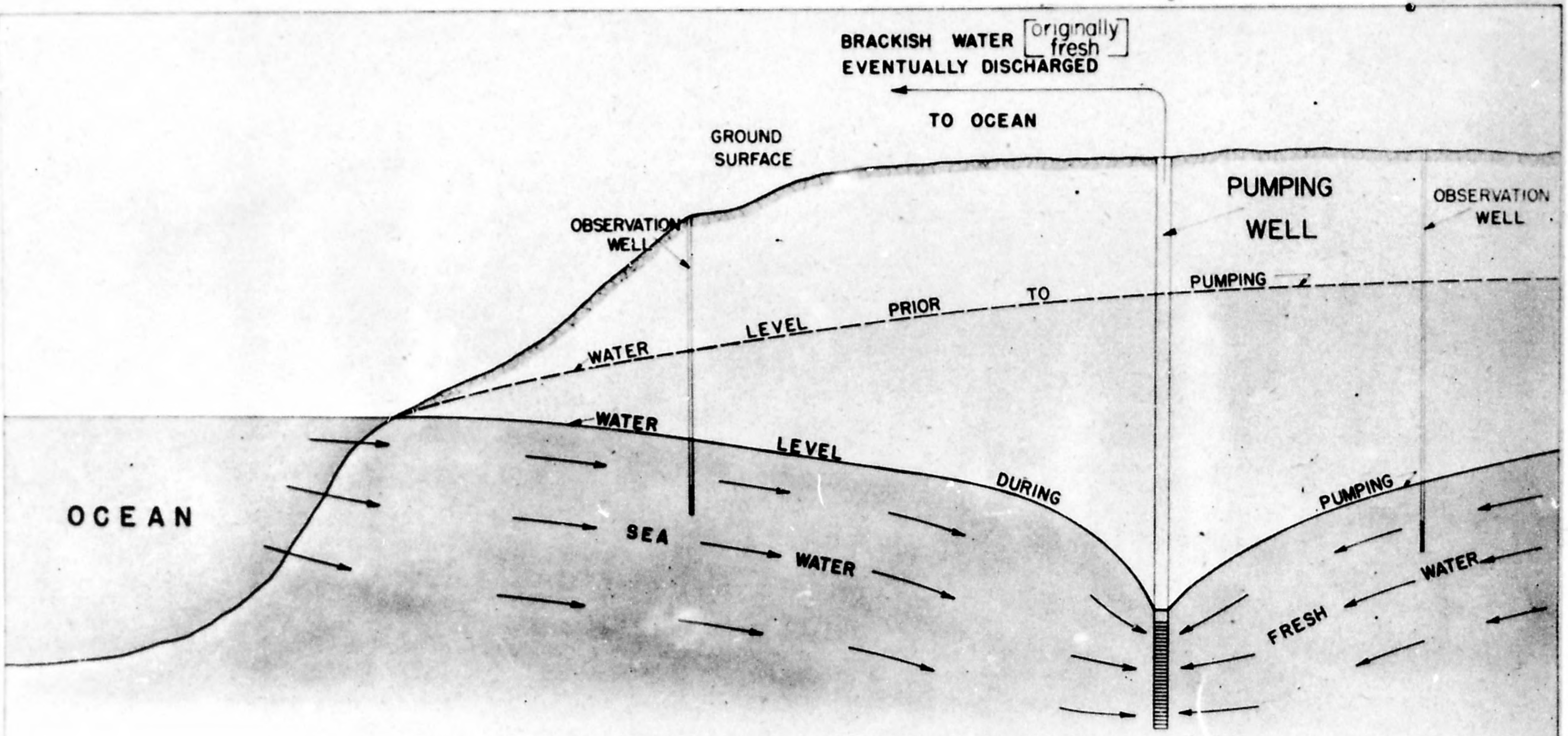
FIGURE 3



SECTIONS SHOWING EXAMPLE OF INDUCED INFILTRATION OF RIVER WATER, RESULTING FROM PUMPING A WELL LOCATED ON RIVER BANK

TOP.-- NATURAL CONDITION
BOTTOM.-- PUMPING CONDITION

FIGURE 4

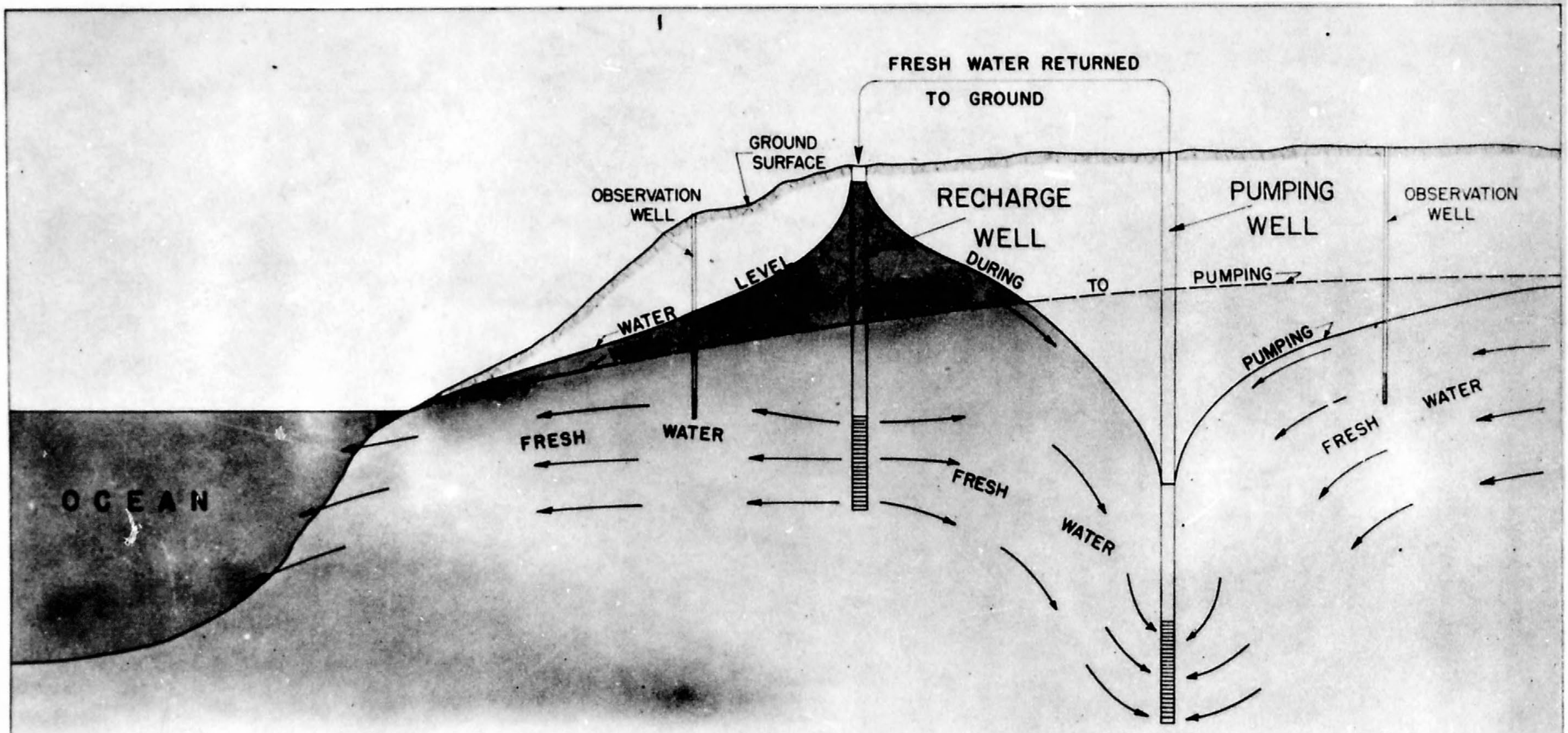


PROFILE SHOWING INTRUSION OF SEA WATER IN VICINITY OF A HEAVILY PUMPED WELL WHICH WASTES WATER TO OCEAN

LOWERING OF WATER LEVELS AND INCREASE IN SALINITY OF GROUND WATER DETERMINED FROM DATA OBTAINED AT OBSERVATION WELLS

64212

FIGURE 5



PROFILE SHOWING PREVENTION OF INTRUSION OF SEA WATER BY USING RECHARGE WELL IN CONJUNCTION WITH HEAVILY PUMPED WELL

TREND OF WATER LEVELS AND SALINITY OF GROUND WATER DETERMINED FROM DATA OBTAINED AT OBSERVATION WELLS

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FIGURE 6

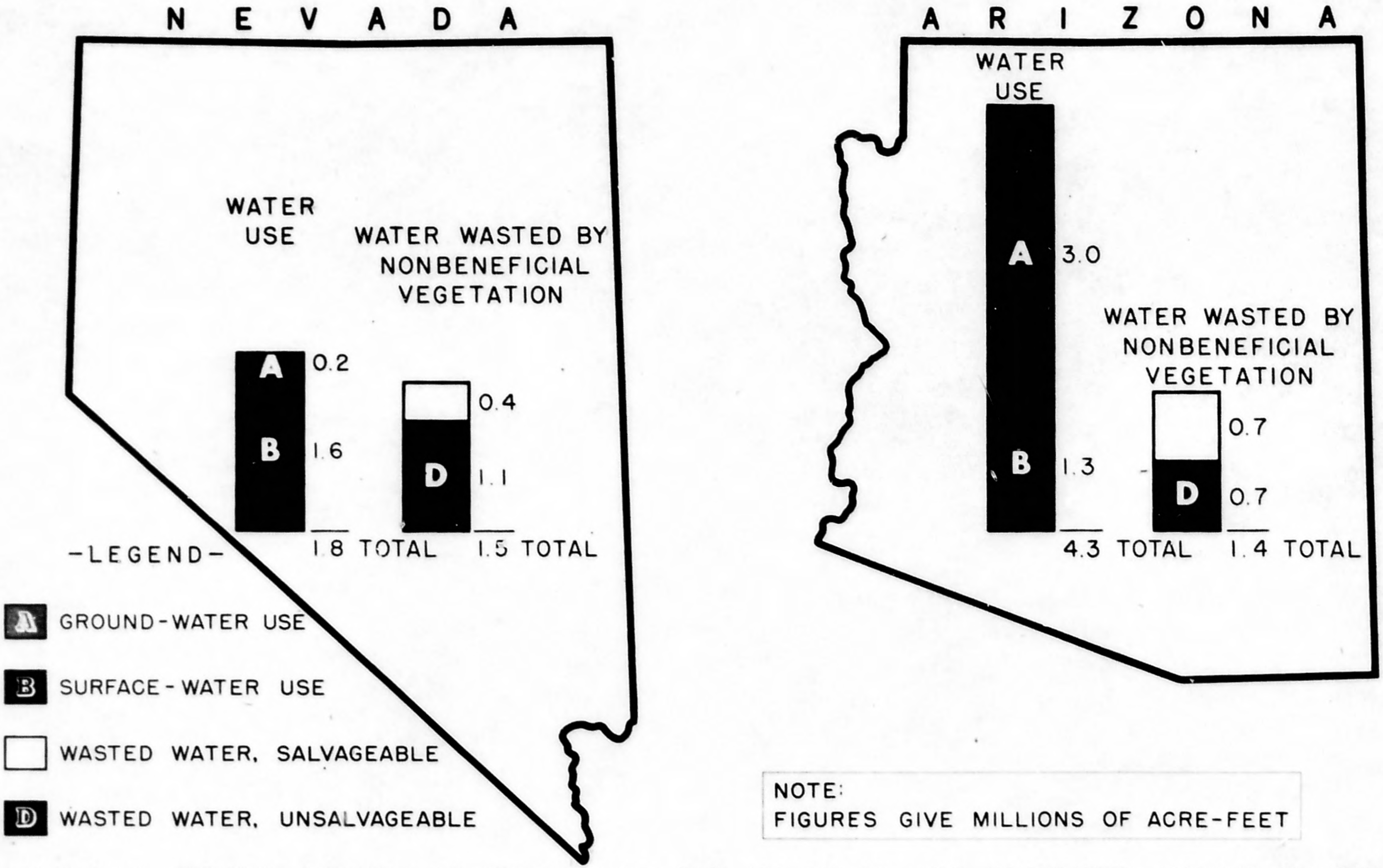
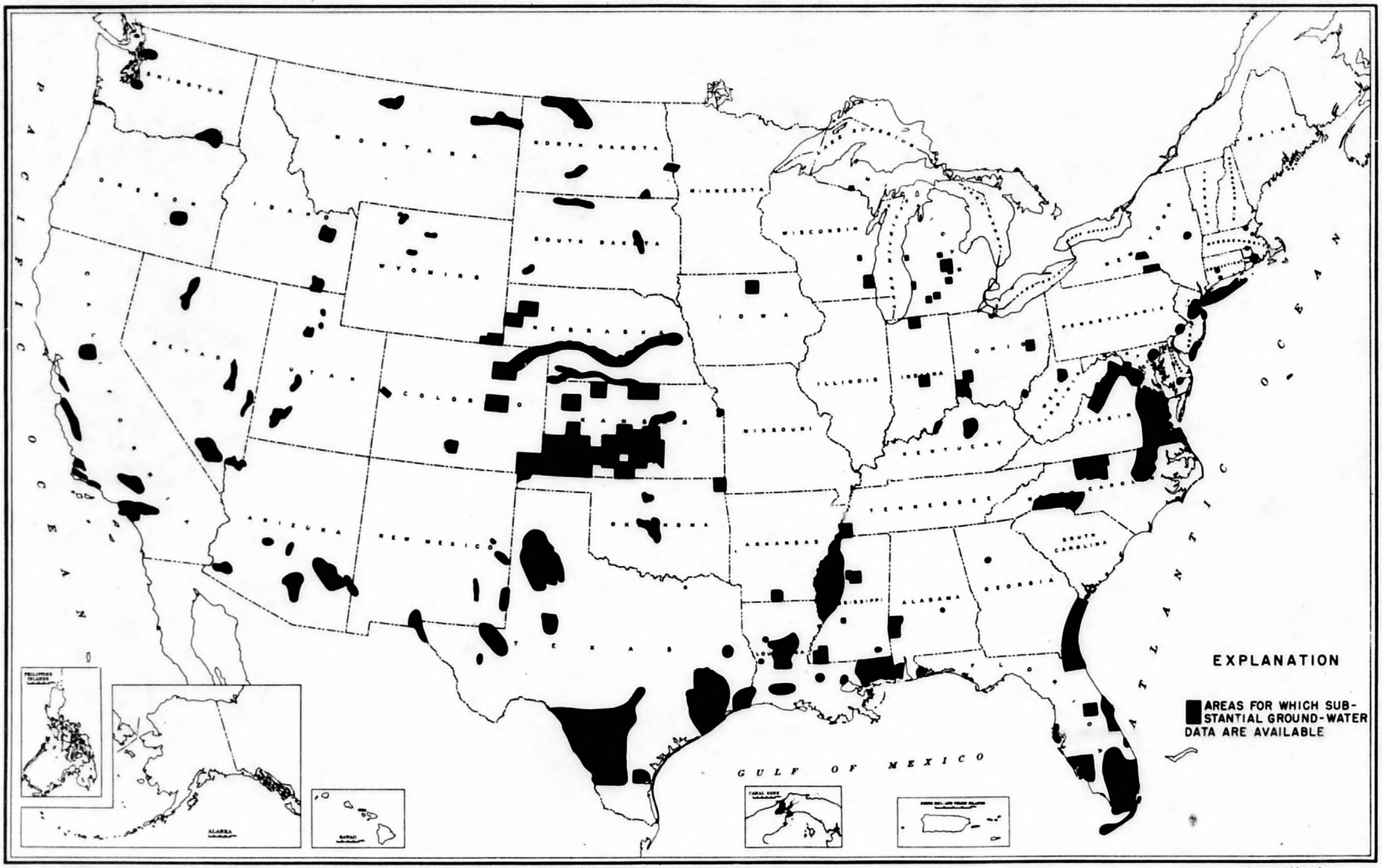


DIAGRAM SHOWING AMOUNT OF WATER USED FOR IRRIGATION AND ESTIMATED AMOUNT OF WATER WASTED BY NONBENEFICIAL, WATER-LOVING VEGETATION IN NEVADA & ARIZONA DURING 1948

FIGURE 7



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AREAS OF SUBSTANTIAL OR COMPREHENSIVE GROUND-WATER DATA

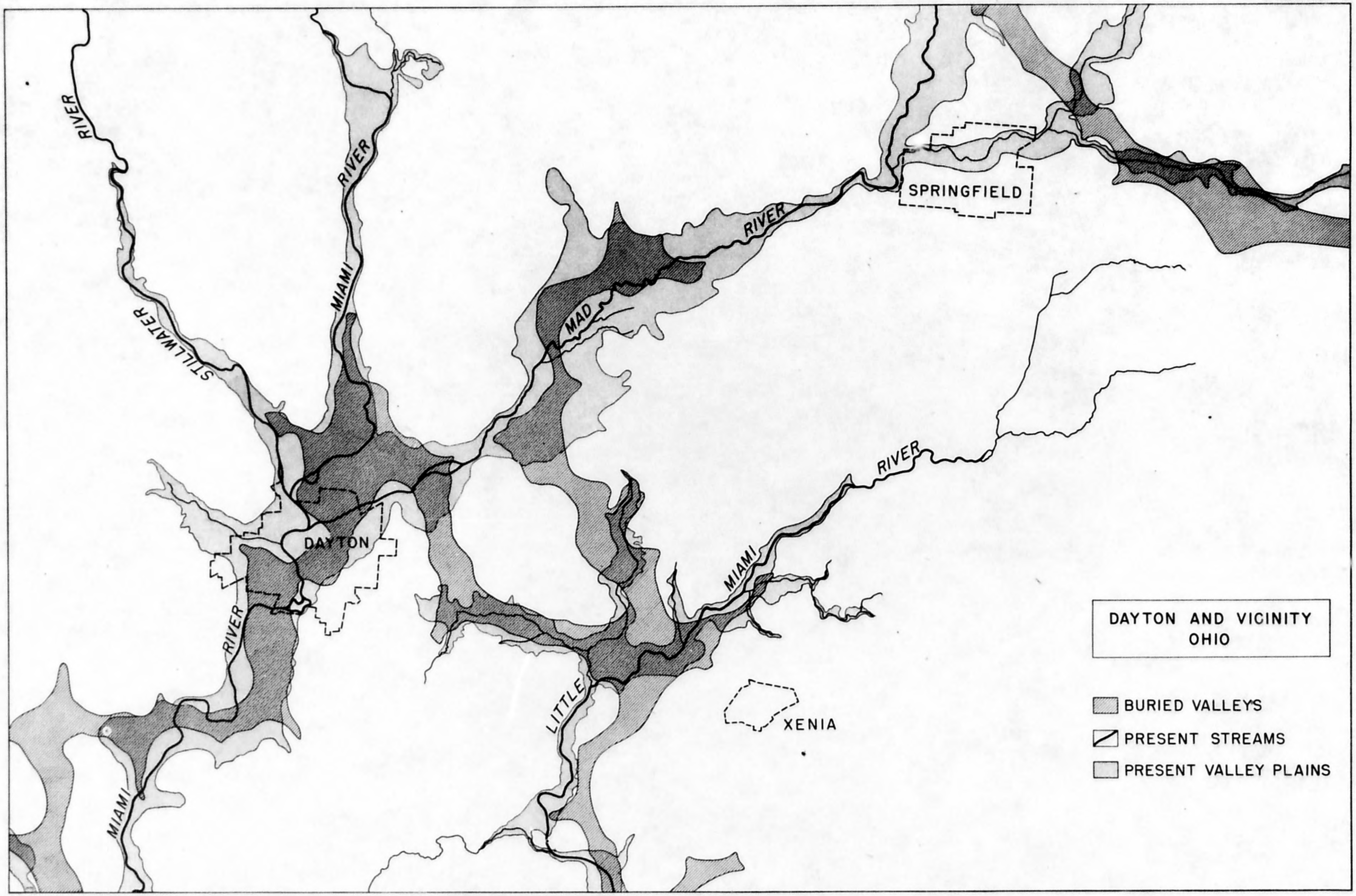
RIVER
STILLWATER
MIAMI
RIVER
MAD
RIVER
SPRINGFIELD
DAYTON
RIVER
MIAMI
MIAMI
RIVER
LITTLE
XENIA
DAYTON AND VICINITY
OHIO
BURIED VALLEYS
PRESENT STREAMS
PRESENT VALLEY PLAINS

FIGURE 9

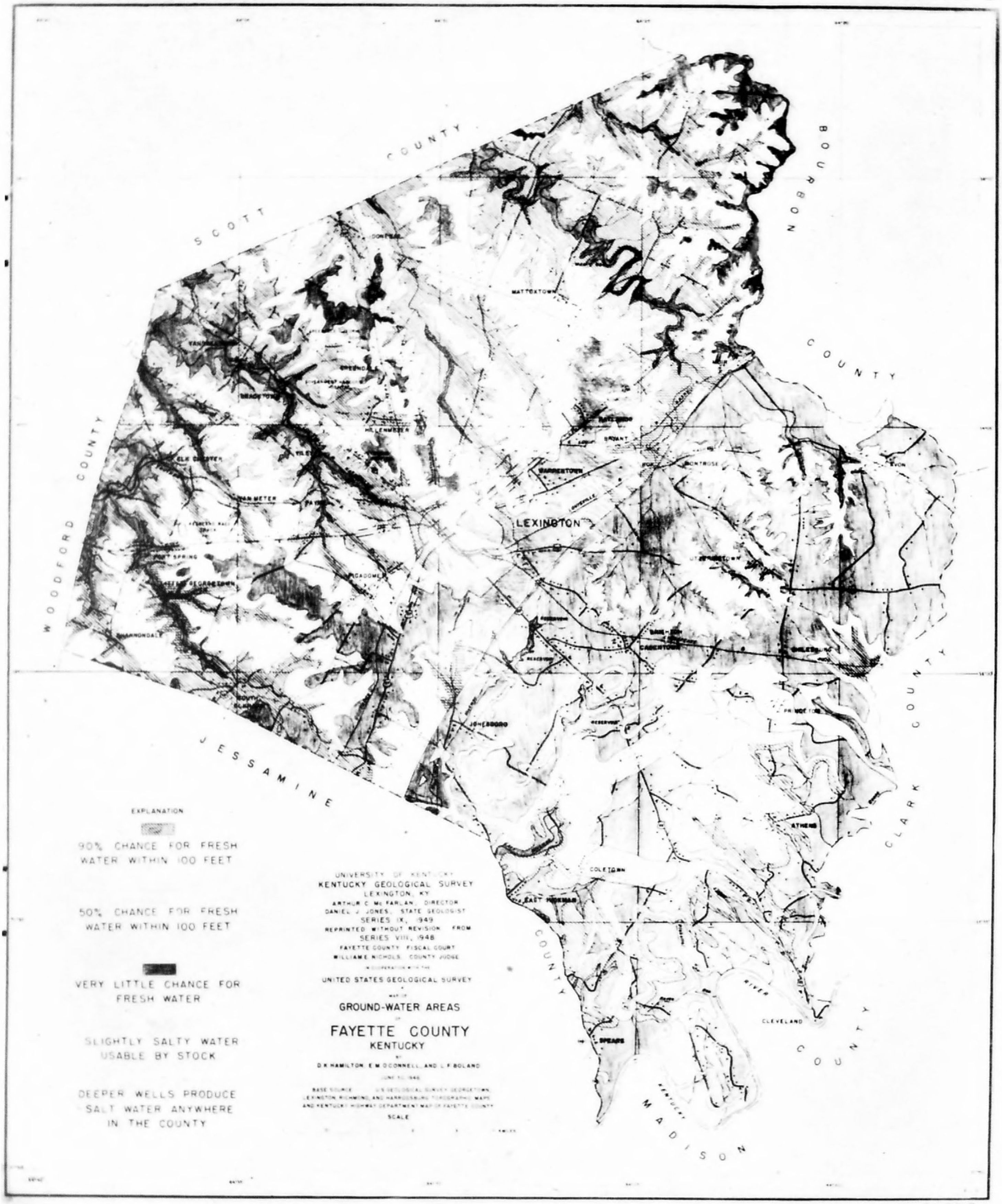

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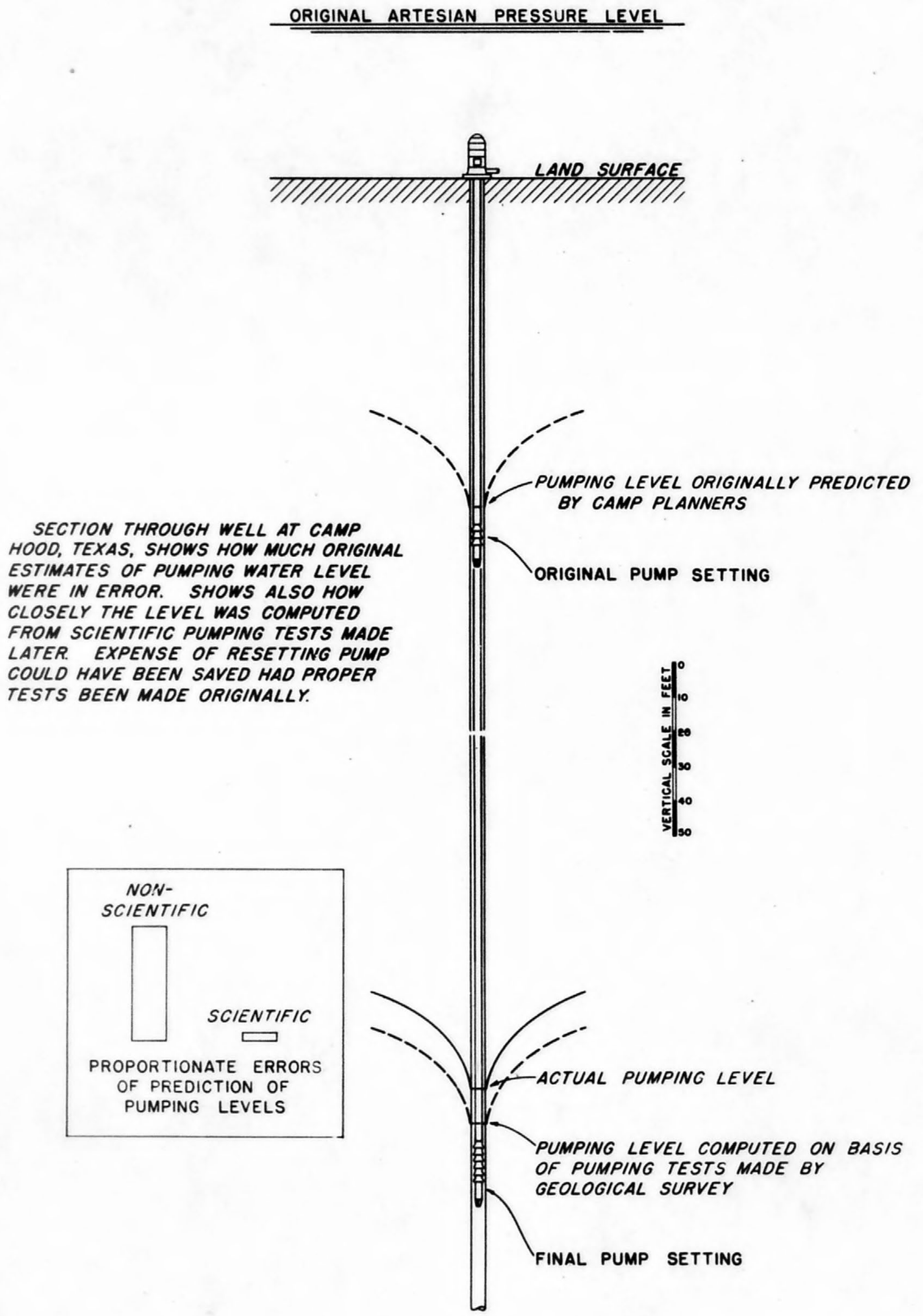
FIGURE 10



DIAGRAMMATIC CROSS SECTION SHOWING USE OF SCIENTIFIC KNOWLEDGE IN WATER-SUPPLY DEVELOPMENT

64212