U.S. Geological Survey.
Ground-water resources of Arizona. No. 9

United States

Department of the Interior

Geological Survey

Geology and ground-water resources of the Salt River Valley area, Maricopa and Pinal Counties, Arizona

by

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Prepared in cooperation with
Arizona State Land Department
O. C. Williams, Commissioner

Tucson, Arizona

FEB 4 1947

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INTRODUCTION

Purpose and cooperation

The Arizona State Legislature has recognized the increasing need in recent years for State regulation of ground-water resources in Arizona. Inasmuch as such regulation must be based upon adequate information as to the quantity, quality, and use, as well as the source and movement of the ground water, the Arizona State Legislature in 1945 appropriated funds for the investigation of the ground-water resources of the State. The investigation is being made by the Geological Survey, United States Department of the Interior, under a cooperative agreement with the Arizona State Land Department, O. C. Williams, Commissioner.

Field work in the Salt River Valley area was started about December 1945 and was done by F. I. Bluhm, H. R. McDonald, J. P. Mooseau, Jr., and M. C. Williams, engineers, and by R. H. Wolcott, geologist, under the general direction of S. F. Turner, District Engineer (Ground Water) of the Geological Survey. Water analyses were made by J. D. Hem and R. T. Kiser, chemists, under the general direction of C. S. Howard, District Chemist of the Geological Survey.

Location

The area included in this investigation is generally known as the Salt River Valley. The boundaries of the area are described as follows: from the Ashurst-Hayden Dam on the Gila River westward along the river to the Gillespie Dam; thence northward along a line approximating the channel of the Hassayampa River to the Wickenburg Mountains; thence eastward on a line along the foothills and mountains that form a part of the upper drainage area of New River and Cave Creek, to the north end of the McDowell Mountains; thence southeastward along the McDowell Mountains through Granite Reef Dam on the Salt River; and thence along the foothills of the Superstition Mountains to the Ashurst-Hayden Dam. The area lies principally in Maricopa County, but a part along the south and east margins lies in Pinal County. The area is a part of the broad, flat plain that occupies a large portion of southern Arizona.

Climatological data

Table 1 gives a summary of the climatological data at the Phoenix station of the U. S. Weather Bureau. The climate at Phoenix, which lies in the center of the area, is characterized by hot, dry summers and short, mild winters. Summer temperatures frequently exceed 110 degrees Fahrenheit, but the low relative humidity causes the temperature to seem several degrees lower. Evaporative coolers have come into almost universal use for homes and public places during the last few years because of the high summer temperatures and the low relative humidity.

The average annual precipitation during the 49 years of record at Phoenix is 7.94 inches. It usually occurs as rain, and snow falls only at rare intervals. Most of the precipitation occurs during two periods of the year; one during July, August, and September and the other during December, January, and February. The summer precipitation is characterized by violent local thunderstorms of short duration with high rainfall intensities. The winter storms usually cover a large general area, are of longer duration, and have lower rainfall intensities.

History of development

Agricultural and industrial development in the Salt River Valley has been almost directly proportional to the quantity of available water. Irrigation was practiced in the Salt River Valley by prehistoric Indian tribes. Water from the river was diverted by crude rock and brush dams into canals constructed by hand labor. The earliest white settlement in the area was established about 4 miles east of the present town of Phoenix in 1868[1]. The newspaper Prescott Miner of August 27, 1870, carried an advertisement of hay and grain for sale at Phoenix Station. Irrigation agriculture, therefore, must have followed soon after settlements were founded. The surface-water supply for irrigation was not assured until after the construction of Roosevelt Dam on the Salt River in 1910. As the supply of water became more dependable, the cultivated area grew rapidly and it was soon apparent that more water was necessary to meet the ever-increasing demand. Consequently, to provide additional storage on the Salt River, Mormon Flat Dam was constructed in 1925, Horse Mesa Dam in 1927, and Stewart Mountain Dam in 1930. On the Verde River, Bartlett Dam was completed in 1939 and Horseshoe Dam in 1945. These six reservoirs have a total combined storage capacity of 2,081,560 acre-feet.

Development of ground-water supplies was not great until about 1922, when the total water pumped for irrigation exceeded 100,000 acre-feet. In 1904, Lee[2] estimated the combined capacities of existing pumping plants in the Salt River Valley to be 4,000 miners inches, or 100 cubic feet per second. On the assumption that the pumps were operated 24 hours a day for 6 months, the total water pumped was about 36,000 acre-feet in 1904. In 1913 the water table was within 10 feet of the land surface in about 12 percent of the Salt River Project, operated by the Salt River Valley Water Users' Association (see table 2). About 1920 it became apparent that recharge to the ground-water reservoir from irrigation and canal seepage was causing an increasingly large amount of land to become waterlogged. At this time the water table was within 10 feet of the land surface in about 31 percent of the Salt River project. Wells were then drilled, first for the purpose of lowering the high water table and later for supplemental irrigation. Pumping and other factors caused the water table to decline, and this downward trend has continued almost without interruption in most of the area, except during or following years of exceptionally high precipitation.

Agriculture and the processing of agricultural products are the largest industries in the area, although in recent years light manufacturing and processing have shown large gains. About 360,000 acres was under cultivation in 1945, and none of this land was irrigated entirely by surface water. The principal crops, with approximate acreages of each, are shown for 1945:

Alfalfa	155,000 acres
Grain	90,000 "
Truck crops	50,000 "
Cotton	41,400 "
Citrus	19,000 "

Phoenix, the largest city in the area, had a metropolitan population estimated in 1944 to be 160,000.

1/ Barnes, Will C., Arizona place names: Univ. Ariz. Gen. Bull. 2, Vol. 6, No. 1, p. 327, Jan. 1, 1935.

2/ Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, p. 175, 1905.

Previous investigations

Earlier studies by the Federal Geological Survey in the Salt River Valley are described in the following reports:

Surface-water resources:

1. Surface water supply of the Colorado River Basin: U. S. Geol. Survey water-supply papers for each year beginning with 1899.

Geology and ground-water resources:

1. Lee, W. T., The underground waters of Gila Valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 104, 1904.
2. Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, 1905.
3. Meinzer, O. E., and Ellis, A. J., Ground water in Paradise Valley, Ariz.: U. S. Geol. Survey Water-supply Paper 375-B, 1916.
4. Ross, C. P., Routes to desert watering places in the lower Gila Region, Ariz.: U. S. Geol. Survey Water-Supply Paper 490-C, 1922.
5. Ross, C. P., The lower Gila region, Ariz.: U. S. Geol. Survey Water-Supply Paper 498, 1923.
6. Turner, S. F., Halpenny, L. C., Babcock, H. M., and Morrison, R. B., Ground-water recharge from flood waters of Queen Creek, Ariz.: U. S. Geol. Survey, report to U. S. Engineer Dept., 45 pp., 6 fig., 2 pl., 1940.
7. Babcock, H. M., and Cushing, E. M., Recharge to ground water from floods in a typical desert wash, Pinal County, Ariz.: Am. Geophys. Union Trans., pp. 49-56, 1941.
8. Babcock, H. M., and Morrison, R. B., Ground water in Skunk Creek area, Maricopa County, Ariz.: U. S. Geol. Survey confidential report to War Department, 1941.
9. Babcock, H. M., Memorandum regarding underflow of the Hassayampa River (manuscript report in files of U. S. Geol. Survey).
10. Babcock, H. M., and Halpenny, L. C., Records of wells, well logs, water analyses, and map showing locations of wells, Queen Creek area, Maricopa and Pinal Counties, Ariz.: U. S. Geol. Survey, (mimeographed), 51 pp., 1 pl., 1942.
11. Turner, S. F., and others, Ground-water resources of the Queen Creek area, Pinal County, Ariz.: U. S. Geol. Survey water-supply paper in preparation.
12. Collins, W. D., Howard, C. S., and Love, S. K., Quality of surface waters in the United States, 1941: U. S. Geol. Survey Water-Supply Paper 942, p. 65, 1942.
13. Turner, S. F., and others, Ground-water resources of the Santa Cruz Basin, Ariz.: U. S. Geol. Survey (mimeographed), 84 pp., 4 fig., 5 pl., 1943.
14. McDonald, H. R., and Padgett, H. D., Jr., Geology and ground-water resources of the Verde River Valley near Fort McDowell, Ariz.: U. S. Geol. Survey, (mimeographed), 99 pp., 14 fig., 5 pl., 1945.
15. McDonald, H. R., and Bluhm, F. I., Further investigations of the ground-water resources of the Verde River Valley near Forst McDowell, Ariz.: U. S. Geol. Survey, (mimeographed), 20 pp., 2 pl., 1946.

16. Water levels and artesian pressure in observation wells in the United States, part 6, Southwestern States and Territory of Hawaii:

    Calendar year 1940: Water-Supply Paper 911, pp. 72-83, 1941.
    Calendar year 1941: Water-Supply Paper 941, pp. 48-55, 66-80, 1942.
    Calendar year 1942: Water-Supply Paper 949, pp. 31-36, 44-56, 1943.
    Calendar year 1943: Water-Supply Paper 991, pp. 47-52, 59-69, 1945.
    Calendar year 1944: Water Supply Paper 1021 (in preparation).
    Calendar year 1945: Water-Supply Paper (in preparation).

Acknowledgments

Valuable assistance was rendered by the organized irrigation districts in the Salt River Valley, and by many well owners, who made their records available for use in the preparation of this report.

GEOLOGY AND ITS RELATION TO THE OCCURRENCE AND MOVEMENT OF GROUND WATER

Maps and field work

The geological work done in this investigation was, of necessity, of a reconnaissance nature. The large area covered and the limited time available prohibited any detailed work, although many localities were noted in which further geological study would be desirable. Field work was done during the period February to November 1946.

The geologic mapping of the area was done mainly on contact prints of aerial photographs. In the eastern portion of Paradise Valley and in the Usery and Orchai Mountains, where aerial photographs were not available, topographic maps of the Federal Geological Survey were used. Arizona Highway Planning Survey maps were combined to make the base map, plate 1.

Land forms and drainage

The area included in this investigation is part of the Basin and Range province[3/], which occupies a large part of the southwestern United States. The land surface of the area is made up of broad, gently sloping, connected valleys or plains from which rise numerous isolated hills and mountain ranges. It is bordered on the north by rugged mountains that separate it from the high plateau country. Most of the area described in this report is drained by the Salt River, but a small portion on the east and south is drained by the Gila River.

The mountains within the valleys are generally rugged and steep, although they attain only moderate altitudes. Maximum altitudes probably do not exceed 3,000 feet above the land surfaces of the adjoining valleys. Numerous small, isolated hills, which project only a few feet or a few hundred feet above the surrounding valley fill, probably represent peaks of small mountain ranges or spurs that have been almost buried in alluvial material.

3/ Fenneman, N. M., Physiographic divisions of the United States: Assoc. Am. Geographers Annals, vol. 6, pp. 19-98, 1916.

Some of the tributary valleys in the area are designated by different names, such as Paradise Valley and Deer Valley, but there is no actual physiographic division between the tributary valleys and the large plain of the Salt River Valley. The valley surfaces throughout the area are interlaced with shallow, branching drainage channels, many of which have been obliterated by cultivation. Small stream channels usually finger out and disappear within a short distance from the mountain areas, and even some of the larger streams, such as Cave Creek and Queen Creek, lose their identity before they reach the Salt or Gila Rivers. Drainage divides, except in the mountain areas, are low and indefinite, and much of the land surface at present is in a stage of comparative stability, neither being eroded nor being built up.

There are no perennial streams in the Salt River Valley. All surface water is stored and diverted by dams and distributed over the cultivated portions through an extensive system of irrigation canals.

Geologic history

The geologic history of this region, prior to the Tertiary period, is comparatively obscure. Little can be deduced as to what occurred during pre-Cambrian time because most of the area is covered by younger volcanic rocks and alluvial deposits. The pre-Cambrian rocks, however, constitute the predominant formations in most of the mountain ranges within the area, and it is possible to draw some general conclusions concerning the history of these old formations.

Sedimentary rocks thousands of feet in thickness now represented by the metamorphosed rocks of the area were deposited in early per-Cambrian time. These sedimentary rocks were broken and subjected to extreme displacement and metamorphism by batholithic intrusions of granite. Major faulting and block movement produced structural featues of which some can still be seen in the mountain ranges of the present time. Following these structural changes, but prior to the beginning of the Tertiary period, there was a long interval of erosion that reduced the irregularity of the land surface to some extent. Any sediments that may have accumulated in the valleys during this interval were either eroded away during subsequent uplifts of the land surface or were so deeply buried by later sediments that no trace of them has been found. So far as is known, no Paleozoic or Mesozoic fossils have been found in the sediments penetrated by deep well drilling.

The Tertiary period was marked by major faulting and by strong volcanic activity that produced widespread flows of lava and subordinate pyroclastic rocks. The deposits followed one upon another until, in places, they reached an aggregate thickness of many hundreds of feet and covered much of the older rock surface. It is probable that a large part of the lavas flowed from fissures. This is indicated by the prevalence of dikes of Tertiary volcanic rocks and by the scarcity of volcanic craters or necks. However, some of the rocks undoubtedly originated from violent eruptions. The dikes and the near-horizontal attitude of the lava flows, where they have not been disturbed by block tilting, indicate that the flows came from numerous sources close at hand.

The total effect of Tertiary vulcanism upon the older land surface was of great magnitude. Some of the lower mountain ranges were entirely covered and the intervening valleys were filled with lava. Stream courses were changed or, in some places entirely blocked. The latter condition resulted in the formation of temporary lakes or playas in which clays and other fine sediments were deposited. Remnants of these sediments occur along the upper reaches of some of the streams that enter the Salt River Valley, notably along the Agua Fria and Verde Rivers. Younger alluvium has covered any sediments that may have been deposited in a similar manner in the main Salt River Valley, but some of the clays encountered in the deeper wells in this area may be reasonably attributed to lacustrine deposition[4/].

At some time during the Tertiary period, probably near the start, began the uplift which formed the high plateau country that extends northward and eastward from the escarpment now known as the Mogollon Rim. Accompanying the uplift of the land surface on the north, there was a gradual but widely-extended subsidence of the area south and west of the escarpment. The combined effect of these land movements was deep erosion of the highland country north of the Salt River Valley and south of the Mogollon Rim and a correspondingly rapid filling of the valley areas to the south. These land movements were probably of greater importance in the accumulation of the immense deposits of valley fill than were climatic changes. Lee[5/] states that:

> "The immense deposits of upland accumulation in this region are best explained as due to subsidence of the surface.* * * However much desiccation of the climate may have caused a diminution of streams and consequent deposition of debris in valleys which were formerly swept clear by these streams, it can not wholly account for this accumulation."

During the subsidence, streams in this area were again diverted to new courses. Old channels became filled, volcanic barriers were breached, and beds of stream gravels were left high above the old channels as the streams cut downward. It was during this period of rapid filling of the valleys and heavy erosion of the uplands that some of the main tributaries of the Salt and Gila Rivers and, indeed, possibly the main streams themselves, may have occupied channels far from their present courses. The interruption of normal stream flow probably was continued in the Quaternary period by thin but widely-extended flows of Pleistocene basalts. Lacustrine deposits may be seen along the Black Canyon Highway a short distance south of the line between Maricopa and Yavapai Counties. There is strong evidence that the Agua Fria River and New River emeraged as a single stream from the lake in which these deposits were formed and followed a southeasterly course into Paradise Valley[6/].

It is also reasonably certain that the Salt River at one time followed a course east of the Salt River Mountains, and that it joined the Gila River at a point south or southwest of the present town of Chandler. Sediments were built up until the stream was diverted through the gap in the hills in the vicinity of the present town of Tempe, whence it followed its present course north of the Salt River Mountains.

Less conclusive evidence indicates the possibility that the Hassayampa River may have been diverted by a temporary volcanic barrier into a channel north of the White Tank Mountains.

4/ Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, p. 114, 1905.

5/ Idem., p. 115.

6/ McDonald, H. R., Wolcott, H. N., and Bluhm, F. I., Geology and ground-water resources of Paradise Valley, Maricopa County, Ariz.: U. S. Geol. Survey water-supply paper (in preparation).

A lava barrier that, at one time, existed in the vicinity of the present town of Florence could have diverted the Gila River to the north of the present channel and caused it to follow a course similar to that now taken by lower Queen Creek.

The hypotheses regarding the courses of the Agua Fria and New Rivers, and of the Salt, Gila and Hassayampa Rivers cannot be proved without much additional study, and in some cases it may be impossible to establish them as either valid or false. However, they should not be overlooked as factors that might have a bearing on present ground-water conditions.

The Quaternary period was marked in this region by greatly dimished vulcanism and faulting. Lava was ejected from the earth, generally in the form of quiet flows. In some places the flows came from reopened Tertiary fissures. These lavas consisted largely of vesicular olivine basalt, and they were much smaller in volume than those of the Tertiary period. As a rule they spread out in relatively thin sheets over flow surfaces of older lavas or upon beds of Pliocene (late Tertiary) sediments. That the flows were intermittent, probably throughout most of the Pleistocene, is proved by the fact that in many places they are interbedded with layers of Quaternary sediments. Whether or not any of these lavas were laid down in Recent time remains an unanswered question. Indian legends place some of the flows within the memory of man, but the extent to which the lavas are altered and weathered casts doubt upon the reliability of those tales.

During the Quaternary period the climate has gradually changed to that of today. With increasing aridity, and probably with the ending of the general subsidence of the land surface in this region, erosional processes were retarded and the valley fill approached the level it now assumes. Stream gravels, lacking water to move them, partially disintegrated where they lay, and rainfall and wind action spread the finer particles evenly over the ground surface to form the parent material of the soil.

Structure

Faulting has played an important part in producing the land forms of this area but folding has been slight. Faulting began with the pre-Cambrian batholithic intrusions of granitic rocks, and it has doubtless continued into Recent time. During the Tertiary period it probably reached maximum intensity. Evidences of fault action are numerous, but it is usually difficult or impossible to trace the actual line of movement because most of the area is covered by alluvium. Even in the mountains, where the hard rock formations are exposed, the character of the rocks makes fault lines inconspicuous.

The main Salt River Valley, as well as many of the tributary valleys, was probably formed by the filling of structural troughs after block-faulting and tilting had produced the troughs and the high rock ridges of the mountain ranges. Structural trends in this region are predominantly to the northwest, although there are numerous local exceptions. One of the notable exceptions to the common trend is the Salt River Mountain range, the long axis of which extends from the Gila River northeastward toward Tempe. Even in these mountains, however, the minor fractures conform to the predominant structural trend.

It is impossible to determine the detailed configuration of the bedrock floor that underlies the valley fill in this area. It is safe to assume, however, that it is extremely uneven. The many small, isolated patches of solid rock at various places in the valley represent the high points of hills or ranges that have been almost buried by alluvium. There are doubtless numerous localities in the area where the buried bedrock is near the surface of the valley fill, but it is believed that none of these buried ranges or hills in the main valley are of sufficient extent or continuity to constitute a completely effective ground-water barrier.

The line of rock outcrops that extends from the hills northwest of Tempe southwest to the Salt River Mountains (pl. 1), suggests the existence of a series of ground-water barriers. An almost complete barrier exists between two of these outcrops; that is, between Tempe Butte and the low hills directly northwest, across the Salt River.

The andesite that forms the crest of Tempe Butte appears to be the same kind of rock as that which forms Bell Butte, approximately 2 miles southwest. This suggests that a ground-water barrier lies between these buttes. However, limited geophysical exploration in this locality failed to show any shallow hard-rock barriers, and a ground-water contour map prepared by the Salt River Valley Water Users' Association, from data collected in 1945, shows no change in slope of the water table through this locality.

Between Bell Butte and the Salt River Mountains, geophysical probing indicated that a buried spur of hard rocks extends about half a mile northeast from the Salt River Mountains. Limited additional probing failed to encounter any shallow hard-rock barriers between this spur and Bell Butte. The ground-water contour map does not indicate a change in slope of the water table through this gap.

Lee[7/] states that, at the time of his investigation in 1904, the water table sloped steeply to the west through the gap between Bell Butte and Tempe, as shown by a difference in water level of 16 feet in half a mile. Lee also noted that the water table sloped steeply to the west between Bell Butte and the Salt River Mountains, as shown by a difference in water level of 10 feet in a quarter of a mile. As a result of these observations, he concluded that:

> "It is evident, all things considered, that the underflow so voluminous and extensive in the Mesa region does not find free passage to the Phoenix region past Tempe."

The disappearance of the break in the water-table gradient since Lee's investigation does not in any way weaken his hypothesis. Present ground-water conditions in this area may best be explained by assuming the existence of a constricted passage rather than a continuous barrier.

Detailed geologic study and further geophysical work followed, possibly, by some test drilling, would be needed to determine the exact character and distribution of the hard rocks in the Camelback-Papago Park-Tempe area, and the effect of these rocks upon the movement of ground water.

Pediments

Hard-rock pediments, of the type described by Bryan[8/], exist in various places along the mountain borders. Wherever these pediments are easily discernible or of considerable extent, they are formed upon granitic rocks. Among the more extensive areas are: (1) An area between the San Tan

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7/ Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, p. 123, 1905.

8/ Bryan, Kirk, Erosion and sedimentation in the Papago Country, Ariz.: U. S. Geol. Survey Bull. 730-B, pp. 52-65, 1922.

Mountains and the Gila River in T. 4 S., Rs. 7 and 8 E.; (2) along the southwestern and western border of the White Tank Mountains in Ts. 1 and 2 N., R. 4 W.; (3) at the base of the hills northeast of Morristown in T. 6 N., Rs. 2 and 3 W.; and (4) along the southern base of the Usery and Orohai Mountains in Ts. 1 and 2 N., Rs. 6, 7, and 8 E. Another large granite pediment area lies between the north end of the McDowell Mountains and Cave Creek Station[9/].

Rock formations

Pre-Cambrian rocks

The pre-Cambrian rocks that border and underlie the Salt River Valley region include schists, gneisses, quartzites, slates, shales, and granites.

Schists of various kinds are a major component of many of the mountain ranges of the region. Some of the schists in the Phoenix, McDowell, and Hieroglyphic Mountains are of probable sedimentary origin, and it is likely that these schists, together with associated quartzites, slates, and shales, are the oldest rocks in the region. The schists range in color from very dark gray or brown to light gray or buff. Lamination is usually distinct and is greatly accentuated by weathering. The schists of the Phoenix and McDowell mountains show a well-defined and fairly uniform northeast strike and a steep dip that, in general, is only a few degrees from vertical. In other mountains in this area a similar strike trend is common, but variations are numerous. Alteration of the original mineral constituents of the schists has resulted in the formation of sericite, muscovite, chlorite, and epidote. Jasper and pods or small lenses of milky quartz are common.

In the Salt River Mountains and the White Tank Mountains, as well as in numerous other localities, the schists are clearly derived from metamorphism of the biotite-granite that occurs in the same ranges. These schists would logically be considered as younger in age than the schists of sedimentary origin, but both types may be assigned with confidence to the pre-Cambrian. The schists of igneous origin are, in general, less thinly laminated than the schists of sedimentary origin, but they exhibit almost as much alteration. The schists of igneous origin easily acquire a characteristic dark brown or black "desert varnish" on their weathered surfaces.

Where schist was exposed in open cuts or mine workings, the rock was observed to be hard and dense within a few feet below the surface. Weathering accentuates the laminations, but this effect apparently is superficial. The value of the schists as aquifers in this region is therefore questionable.

Gneisses are widely distributed throughout the region. They occur as an intermediate step in the metamorphism of the pre-Cambrian granites and frequently grade into igneous schists. Comparatively fresh and unaltered biotite-granite, gneissoid granite with grain distortion that is noticeable but not far advanced, and true banded gneiss occur in close proximity. These transitional zones are numerous through the region and are best exposed in the Salt River and White Tank Mountains. Because of the reconnaissance nature of the geologic work, these transitional zones were not differentiated on the geologic map (pl. 1).

9/ McDonald, H. R., Wolcott, H. N., and Bluhm, F. I., Geology and ground-water resources of Paradise Valley, Maricopa County, Ariz.: U. S. Geol. Survey water-supply paper (in preparation).

The gneisses, like the granites, are impervious except where they are fractured, and they are therefore considered to be of little value in the storage or transmission of water in the region.

Quartzites are of limited extent in the mountains of this region. Small exposures were noted in the McDowell and Phoenix Mountains, where they are associated with schists of sedimentary origin. The largest exposure of quartzite observed was in the Hieroglyphic Mountains (sec. 24, T. 6 N., R. 2 W.). This quartzite forms several parallel ridges that have a total width of approximately 1 mile and a length of more than 2 miles. These ridges are almost black in color and rise sharply out of a lower area of schists. Bedding in the quartzite is indistinct but discernible. The strike is approximately N. 65° E. and the dip is about 70° NW. The rock is fine-grained and is heavily cross-fractured. Hematite, both in an amorphous form and as specularite, is abundant along the fractures.

The quartzite, because of its fractured condition, may be a fairly effective medium for the entry and storage of water, but its comparatively limited area makes it of little hydrologic importance in the Salt River Valley area.

Slates and shales are reported to occur in various localities in this region[10], but they are far from common. The only slate observed during the present investigation was on Black Mountain, directly south of Cave Creek Station. Because of the small area of exposure of this rock, it may be disregarded as a possible aquifer.

Three distinct types of granite have been observed in the Salt River Valley region, although there are numerous local variations. One of the most widely distributed types is a medium-coarse to very coarse-grained, light gray rock composed chiefly of orthoclase feldspar with minor amounts of biotite mica and quartz. Feldspar crystals up to 2 inches in diameter occur in the coarser-grained rock. In some places this granite shows numerous inclusions of a fine-grained porphyritic rock. The granite weathers readily into rounded boulders and forms some of the most extensive rock pediments of the region. Granite of this type is common in the McDowell, Phoenix, and Hieroglyphic Mountains. The surface of this rock is darkened by weathering, but the outcrops are not nearly as dark as those of some of the other granites.

A second widely distributed type of granite is a medium fine to medium coarse-grained rock that contains much more biotite mica and quartz than the first type described. This granite also weathers readily, but the mineral components are generally not highly altered. It is probably the most widely-distributed of the three types. Large areas occur in the Salt River Mountains south of Phoenix, in the Usery and Orohai Mountains north and east of Mesa, in the San Tan Mountains east of Chandler, and in the southern part of the White Tank Mountains north of Buckeye. In numerous localities this granite grades through transition zones into granite-gneiss and finally into schist. These metamorphic effects are particularly noticeable in the Salt River Mountains, where the comparatively unaltered biotite granite in the central part of the range grades almost imperceptibly into banded gneiss and, at the extremities of the range, into schist.

10/ Wilson, Eldred D., Arizona non metallics: Univ. Ariz., Ariz. Bur. Mines Bull. 152, p. 47, 1944.

The third type of granite observed during this investigation is less widely distributed than the other two. It is a coarse-grained rock composed chiefly of pink feldspar, biotite mica, and quartz. This granite generally shows extensive alteration of the mineral components. Chlorite and epidote from the mica and sericite from the feldspar are the most prominent alteration products. Weathering and alteration of the rock constituents result in a distinctive reddish-pink outcrop. This granite occurs in numerous places but individual exposures are comparatively small in area. The most prominent exposures are in Camelsback Mountain, north of Phoenix; in Mount McDowell, at the junction of the Salt and Verde Rivers; and in the eastern end of the San Tan Mountains, east of Chandler.

In the hills between Cave Creek Station and New River, in the vicinity of the Bulldog Mine (secs. 2 and 3, T. 1 N., R. 3 E.), and in other localities, there are small areas of pink granite which, on first glance, appears to be the same as that just described. On close inspection, however, the rock looks like a gray biotite-granite that has been discolored by hematite (iron oxide) stains. Diabase intrusions usually occur near these areas, and the red discoloration may be due to the oxidation of iron-bearing minerals, either in the diabase or in the granite itself.

The granites are not considered to be of value for the storage or transmission of water, because they are impermeable except along fractures.

Tertiary, Cretaceous, and pre-Cretaceous (?) rocks.

Volcanic rocks

Under this heading are grouped partially-metamorphosed volcanic rocks that are probably older than Cretaceous but younger than pre-Cambrian, and volcanic rocks belonging definitely to the Tertiary and Cretaceous periods. There is generally no certain method of distinguishing between Tertiary and Cretaceous lavas in this region. Therefore, these lavas will be considered together.

The partially-metamorphosed pre-Cretaceous volcanic rocks are not as extensive as the Tertiary and Cretaceous volcanic rocks of the region. They are difficult to classify as to age. The two ranges of hills extending northwest from the vicinity of Cave Creek Dam constitute the largest exposures. Metamorphism has been extensive in these rocks and definite schistosity has developed in places. Alteration of the mineral constituents has been extreme, but the general appearance of the rock indicates that it was formerly one of the basic lavas. Epidote and jasper are abundant as alteration products.

The age of these lavas is problematical. They are in contact with both schists and granites, but the actual contacts are covered by soil or weathered debris, making it impossible to determine their stratigraphic relation. Within broad limits, it should be safe to assume that they are younger than pre-Cambrian and older than Cretaceous. They may be related to the diabase that occurs commonly as intrusive dikes in the pre-Cambrian granites and schists.

These lavas are extremely hard and fine-grained, and they have practically no value for ground-water storage except where they are faulted or broken by later intrusions.

Tertiary and Cretaceous lava flows and dikes, or residual evidence of their presence, occur in most of the mountain ranges in the region. These lava flows are widely varied in character, ranging from light-colored acidic rhyolites to dark-colored basic andesites and basalts. Although they have been heavily eroded, some of the lavas still have a thickness of hundreds or even thousands of feet. Probably the largest unbroken mass of volcanic rocks within the region is in the Superstition Mountains, where more than 2,000 feet of successive layers of rhyolites, dacites, andesites, volcanic ash, and tuffs are exposed in the precipitous bluffs at the western tip of the range.

Nearly all the lavas in the region occur as flows, and along eroded borders they generally exhibit well-defined flow structure. They are frequently inclined at a considerable angle, due probably to block faulting and tilting. In a very few places the formations have the appearance of volcanic necks. One of the most prominent of these is a high, conical hill of buff-colored dacite in sec. 35, T. 7 N., R. 2 E., approximately a mile west of New River Station. This hill is almost surrounded at its base by deeply eroded pre-Cambrian schists. There are a few other hills in the region that resemble volcanic necks, and the numerous exposures of tuffs, agglomerate, volcanic ash, and scoria indicate that violent eruptive action occurred in the region.

The alternation of lava flows with volcanic ash and tuff and the abundant joints and fault fractures produce a typical topography where these rocks occur. Flat or gently-sloping hilltops are terminated abruptly by almost vertical bluffs. These sheer bluffs merge into steep talus slopes that gradually flatten out into the valley floors.

In general, the Tertiary and Cretaceous volcanic rocks are impermeable, excert along faults or fracture zones and, considered by themselves, are of little value in the storage and transmission of ground water. Because of their wide distribution, however, they have had a profound effect upon the drainage and upon the formation of the principal ground-water reservoirs of the region.

<u>Sedimentary rocks</u>

There is considerable doubt as to the age of the older sedimentary rocks in this region. Lack of fossils and definite marker horizons makes any age correlation extremely difficult, and it is only by analogy with similar deposits in other regions that the age of these rocks may be inferred. The distinction between the Quaternary deposits and the deposits that are Tertiary or older can be only tentative until fossil evidence or some equally reliable medium of identification is found.

Sedimentary rocks of Tertiary age or older occur in three comparatively small areas in this region. One of these is Mount McDowell, near the junction of the Salt and Verde Rivers. Red conglomerates and sandstones form a prominent bluff which is one of the landmarks in the Salt River Valley. The sediments rest upon coarse-grained pink granite that is similar in appearance to the granite in the main mass of Camelback Mountain.

Two areas of older sedimentary rocks occur on the west end of Camelback Mountain and in the hills that extend from Papago Park south to Tempe Butte. These two areas are probably exposures of a single deposit, but the surface continuity is broken by a covering of later sediments between the two outcrops. On Camelback Mountain the sediments show a rough but very definite bedding that strikes northeast and dips at an angle of approximately 20° NW. At the base, this formation consists entirely of large granite boulders embedded in finer debris of granitic material. Upward, the rock materials become finer-grained and include boulders of volcanic rock and schist. Beds of red santstone and fine-grained conglomerate occur near the top of the formation. The materials in all the beds except those at the base show the rounding effect of stream action, but sufficient angularity is preserved to indicste a nearby source. Cementation has progressed sufficiently to render the whole formation resistant to weathering, but it has not made the rock impermeable. Wells that penetrate this material near the base of the mountain have been successful, showing that it forms a fairly good aquifer.

South of Camelback Mountain the older sediments are covered with younger alluvium. They are exposed again in Papago Park, approximately 3 miles farther south. From this locality they extend almost continuously to Tempe Butte, on the south bank of the Salt River. Here they appear as a series of red sandstones and shales, partially overlain by Tertiary andesite[11/]. The sediments on Tempe Butte probably correspond to the uppermost beds on Camelback Mountain.

In all three localities the older sediments rest, with an erosional unconformity, upon the pink granite that has already been described. All the older sediments are derived largely from this type of granite but contain minor amounts of sediments derived from volcanic rocks and schists. Rounding of most of the particles by water is noticeable but not extreme, indicating that they have not been transported a considerable distance. The lower beds may represent, at least in part, talus deposits formed when the adjacent granite mountains were much higher. The upper, finer-grained beds of sandstone and shale were a result of later erosion and deposition of materials from the same areas. Nothing has been found during the investigation to warrant any definite age correlation of these sediments, but the overlying Tertiary lava on Tempe Butte shows that they are Tertiary or older.

Quaternary rocks

Volcanic rocks

All the Quaternary volcanic rocks in the region are of the same general type. This is a vesicular basalt, usually very dark gray but in some places reddish-brown in color, which occurs in relatively thin and widely-distributed flows. In some places these flows rest unconformably upon pre-Cambrian schists or granites. In other places they cover older flows of Tertiary or Cretaceous lavas, and they also occur interbedded with Quaternary sediments. Their stratigraphic association with Quaternary sediments places these basalts definitely in the Quaternary period. It is possible that future study may add to this classification certain andesitic lavas that have been mapped as Tertiary (pl. 1). The Quaternary flows frequently have layers of scoria (volcanic clinkers) up to a few feet in thickness at their base. In no place have the flows had much effect upon the rocks with which they are in contact. Weathering, possibly along cracks developed in cooling, rapidly reduces these lavas to the rounded boulders and pebbles typical of the so-called "malpais" hills. These boulders and pebbles are usually coated with a characteristic black "desert varnish."

The young basalt flows would appear to offer an excellent medium for the reception of water from rainfall because of their tendency to decompose rapidly as a result of weathering. However, they decompose into clays that form a more or less effective seal against the downward percolation of surface water. For this reason, and because the flows are thin, they are not regarded as important aquifers.

11/ Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, p. 100, 1904.

Sedimentary deposits

The gravels, sands, silts, and clays that constitute the soil and upper layers of valley fill in most of this region are of Quaternary age. Beneath these materials, to depths as yet undetermined, are valley-fill sediments that are probably Tertiary or older. Except for the unconsolidated and unsorted sands and gravels in the stream channels and flood plains, most of the material in the upper layers is considered to belong to the Pleistocene epoch (early Quaternary).

The areal extent of the Pleistocene sediments is great, amounting to several thousand square miles in this region, but the average thickness of these sediments below the valley surfaces cannot be estimated. The thickness is extremely variable, ranging from a few inches up to many hundreds of feet.

The materials in the valley fill were derived from the broken, mountainous country to the north and east and from the isolated ranges within the valley borders. Although some of the component rock fragments are well-rounded, most of them are sufficiently angular to indicate that they have not been transported far. From the extremely irregular manner in which the materials were deposited, it is clear that they were brought in by stream flows of widely varying volume. Lenses and layers of boulders, gravel, sand, silt, and clay are mixed indiscriminately and without continuity (see well logs, table 4). The types of materials at a given level usually show great differences, even in closely adjacent wells.

Layers of caliche exist in the valley fill throughout most of this region. Some of these layers are covered by only a few inches of soil, others have been penetrated in wells at depths of several hundred feet. The layers near the surface are practically impermeable, and they prevent the downward percolation of surface water.

There are wide differences in the degree of consolidation and cementation of the Pleistocene sediments. Some formations are unconsolidated and highly permeable, others are tightly compacted and relatively impermeable. In some localities are hard, firmly-cemented conglomerates or sandstones. Highly productive aquifers have been found in the Pleistocene sediments.

Of great importance in the storage and transmission of ground water are the unconsolidated gravels and sands along the stream channels and flood plains. These are shown on the map (pl. 1) as Recent alluvium. The total area of this material is comparatively small, but doubtless much of the recharge to the ground-water reservoirs in the region occurs through it. Much of the rainfall that is shed from the impermeable rock surfaces of adjacent mountains finds its way to the permeable beds of ephemeral washes, where it sinks rapidly to underground storage. Much of the intermittent stream flow along the main river channels in this region is absorbed in the same manner.

As stream courses changed through the years, the abandoned channels were buried. They still retained their connection, however, with the parent channels and did not lose their capacity to transmit ground water. The distribution of stream gravels through the valley fill was not continuous. Lee[12/] mentions at least two periods of deposition with intervening periods of erosion, and it is probable that there were other erosional cycles. Most of the highly-productive aquifers in this region probably represent old stream channels that were formed as the Salt and

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12/ Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, p. 111, 1904.

Gila Rivers and their numerous tributaries meandered across the valley plains in Pleistocene and Recent times.

GROUND-WATER RESOURCES

Occurrence and movement

Ground water occurs principally in the gravel and sand deposits that constitute a part of the unconsolidated sediments in the Salt River Valley. These deposits are the source of water for most wells in the area. The beds are discontinuous, but that they are interconnected is shown by the fact that the water levels in practically all wells in a given locality stand at a definite level that forms a comparatively uniform plane.

Movement of ground water is always down the slope of the water table. In the principal cultivated areas the slope of the water table closely follows that of the land surface, except in areas where the gradient has been influenced by pumping from wells. Between the margins of the cultivated areas and the mountains, the slope of the water table is less than that of the land surface and the depth to water becomes progressively greater toward the mountains.

The Salt River is generally influent (contributes to the ground-water reservoir) from Granite Reef Dam to a point about 5 miles or a little more west of Phoenix, where it becomes generally effluent (receives water from the ground-water reservoir) to its confluence with the Gila River. The Gila River is influent from Ashurst-Hayden Dam to a point a few miles upstream from Laveen, and from this point downstream to Gillespie Dam it is effluent.

Recharge

Recharge to the aquifers of the region is derived from four main sources, listed in order of importance: (1) Irrigation and canal seepage, (2) stream flow, (3) underflow of major streams where they enter the region, and (4) rainfall,

Irrigation and canal seepage

A part of the water used for irrigation finds its way to the water table unless prevented from percolating downward by some impermeable formation. Probably the greatest recharge to the ground-water reservoir in the Salt River Valley occurs from irrigation and from seepage in canals. The Salt River Valley Water Users' Association reports that 36 percent of all water diverted at Granite Reef Dam is lost before it is delivered to irrigators. However, this loss includes evaporation from the water surfaces of the canals and over-devlivery to the farmers, as well as seepage to the ground-water reservoir. Table 3 shows that between 1915 and 1920 the amount of land in the Salt River Project where the water table was within 10 feet of the land surface had increased from 12 percent to 31 percent of the project area. The increase in the area underlain by a shallow water table was caused primarily by recharge from irrigation and canal seepage. Undoubtedly similar recharge occurs from irrigation in other parts of the valley. Sufficient data are not available to determine the total quantity of recharge to the ground-water reservoir from irrigation and seepage in canals.

Stream flow

A large part of the recharge to the ground-water reservoir of the Salt River Valley is derived from flow in the streams of the region.

Queen Creek

The recharge from Queen Creek to the ground-water reservoir was investigated by the Federal Geological Survey in 1939-1941. Babcock and Cushing[13] state:

"The computed average rate of infiltration over the wetted area for the different floods varied from 0.14 to 2.09 feet per day and averaged 1.08 feet per day. The rate of infiltration for the summer-type flash-floods was less and showed a wider range than those for the winter-type floods. This is attributed to the fact that floods of the summer type are of shorter duration and on the average carry more silt than those of the winter type.

"A comparison of the rates of infiltration over the wetted area between the gaging-stations during floods with the rates determined from the seepage-measurements during moderate to low flows of comparatively clear water is instructive. The average for the floods over the entire stretch was only about one foot a day, while the average for the clear water in the individual parts of the stretch during the seepage-runs was more than four feet a day. The smaller rate of infiltration during the floods was due in part to the large silt-load, carried during the early stages of the flood, and in part to the spreading of the flood-water during large flows upon silty rather impermeable material in areas outside the channels.

"In the seepage-measurements it was noted that the rate of infiltration progressively decreased in a downstream direction as the material in the channel-bottom became progressively finer. It was also observed that during continuous flows of clear water after floods, the rate of infiltration increased with time. For a 2.1-mile stretch between the Upper Gaging-Station and the highway bridge it was 6.18 feet a day on January 29, 6.53 feet a day on January 30, and 6.82 feet a day on January 31, 1941. On March 23, 1941, several days after a large flood, the rate of infiltration for the same reach was 5.98 feet a day, and on March 25, 6.84 feet a day. In each case the water was clear at the Upper Gaging-Station but became progressively muddier downstream, showing that the clear water had sufficient velocity to transport the fine material, leaving the coarser and more permeable material."

Babcock and Cushing also state that during the period from February 12, 1940, to March 13, 1941, about half of the water that entered a 19-mile reach of the Queen Creek channel was recharged to the ground-water reservoir. The total amount of water recharged was about 32,000 acre-feet.

Queen Creek is the only stream in the region in which the ground-water recharge has been studied. However, inasmuch as Queen Creek is similar to certain other streams in the region, such as Cave Creek, and the Hassayampa, Agua Fria, and New Rivers, it is believed that recharge from these streams occurs in a similar manner, although no quantitative

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13/ Babcock, H. M., and Cushing, E. M., Recharge to ground-water from floods in a typical desert wash, Pinal County, Ariz.: Am. Geophys. Union Trans., pp. 49-56, 1941.

estimate can be made.

Gila River

The Gila River is influent in the reach from Ashurst-Hayden Dam to a point a few miles upstream from Laveen. The only stretch of the stream between these two points that can possibly contribute recharge to the Salt River Valley lies upstream from Florence, where there may be underflow northwestward into the Queen Creek area. Turner and others[14] state that the average annual recharge in the reach from Ashurst-Hayden Dam to Sacaton Dam was 16,000 acre-feet between 1934 and 1942.

Hassayampa River

The Hassayampa River is influent from the point where it leaves the mountainous area, 4 miles northwest of Morristown, southward to the junction with the Gila River. Within this reach the Hassayampa River probably contributes considerable recharge to the ground-water reservoir during floods. Until more data are obtained, the quantity of recharge from this river cannot be determined.

Agua Fria and New Rivers

Both the surface flow and the underflow of the Agua Fria River are stored by Carl Pleasant Dam. The water is released into a concrete-lined canal, which delivers it to Maricopa County Municipal Water Conservation District Number 1, for irrigation use. Floods in the New River or in the drainage area of the Agua Fria below Carl Pleasant Dam contribute recharge to the ground-water reservoir. The infrequent overflow from Carl Pleasant Dam also contributes recharge. The quantity of recharge from these streams cannot be determined until more data are obtained.

Cave Creek and Paradise Valley

The recharge from Cave Creek, and Paradise Valley has been discussed by McDonald, Wolcott, and Bluhm[15] in a report on Paradise Valley. They state that the safe yield of the ground-water reservoir in Paradise Valley is about 6,700 acre-feet per year, and that the major part of this is furnished by recharge from Cave Creek. Cave Creek also contributed an unknown amount of recharge from flood flows that passed the Cave Creek flood-control dam.

Salt River

The Salt River is an influent stream from Granite Reef Dam downstream to a point about 5 miles west of Phoenix and, therefore, surface flows in this reach of channel infiltrate rapidly into the sandy stream bed and recharge the ground-water reservoir. Such flows and recharge probably occur only during years of exceptionally heavy runoff, because of the large storage capacity of the six reservoirs on the Salt and Verde Rivers.

14/ Turner, S. F., and others, Ground-water resources of the Santa Cruz Basin, Ariz.: U. S. Geol. Survey (mimeographed), p. 60, 1943.

15/ McDonald, H. R., Wolcott, H. N., and Bluhm, F. I., Ground-water resources of Paradise Valley, Maricopa County, Ariz.: U. S. Geol. Survey water-supply paper (in preparation).

Other streams

The recharge from the smaller streams and drainage channels that enter or originate in the region is not large compared to the recharge from the other sources. However, the total recharge from all of these smaller streams may be substantial.

Underflow

The underflow of major streams where they enter the region does not constitute an important source of recharge to the ground-water reservoir. The underflow of the Hassayampa River, for example, was computed in 1940 by Babcock[16] as less than 0.5 cubic foot per second, or about 300 acre-feet per year, using data obtained by the Bureau of Reclamation, United States Department of the Interior. The determination of permeability on which the estimate is based was made about 5 miles northwest of Morristown, by means of test-pumping a large well and measuring the water levels in numerous observation wells installed in the narrow river channel.

The underflow of the Agua Fria River is intercepted by Carl Pleasant Dam. The underflow of New River is probably less than that of the Hassayampa River. Cave Creek has little or no underflow through the Phoenix Mountains. Granite Reef Dam intercepts the underflow of the Salt River. The underflow of Queen Creek, at the Whitlow damsite, was computed in 1944 as about 0.6[17] cubic foot per second or 440 acre-feet per year.

There is a possibility that some recharge is contributed to the ground-water reservoir by underflow from the Gila River into the Queen Creek area. Data are not yet available to determine whether or not this occurs. The Gila River contributes underflow to the Salt River Valley between the Sierra Estrella and Salt River Mountains. Turner and others[18] state that, in 1940, this underflow was about 4,000 acre-feet per year.

The total underflow from the sources listed is less than 5,000 acre-feet per year. The underflow of other washes that enter the area is not known, but it is probable that the total underflow from all sources into the Salt River Valley is little more than 5,000 acre-feet per year.

Precipitation

A little recharge to the ground-water reservoir may occur directly from precipitation, but in the desert areas the greater part of the rainfall absorbed by the soil is probably lost by evaporation and transpiration[19]. Likewise, precipitation on cropped land probably does not contribute any appreciable quantity of recharge, as the water-holding capacity of the soil is high and the rainfall is largely used by the crops.

16/ Babcock, H. M., Memorandum regarding underflow of the Hassayampa River (manuscript report in files of U. S. Geol. Survey) 1940.

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

18/ Turner, S. F., and others, Ground-water resources of the Santa Cruz Basin, Ariz.: U. S. Geol. Survey (mimeographed), p. 42, 1943.

19/ Idem., pp. 53-61

Discharge

Discharge of ground water from the Salt River Valley occurs both by pumping and by natural means. Natural discharge includes ground water that enters the streams and is discharged as surface flow; it also includes underflow out of the valley and water discharged by evaporation and transpiration. Pumping in any part of the valley affects the ground-water supply of the valley by increasing the amount evaporated and transpired and reducing that discharged as surface flow and underflow.

Pumping

Pumping by the Salt River Valley Water Users' Association (Salt River Project) first exceeded 100,000 acre-feet annually in 1922. Most of the wells drilled prior to 1930 did not greatly exceed 300 or 400 feet in depth but most of the wells drilled in recent years are deeper, ranging from 450 to 900 feet, and averaging about 650 feet in depth. The yield and drawdown of wells differ greatly among individual wells and in different parts of the valley. In 1946 more than 200 well-discharge measurements were made and the discharges ranged from 200 to approximately 6,000 gallons a minute.

The Ground Water Act of 1945, passed by the Arizona State Legislature, required that all irrigation and drainage wells with a capacity of 100 gallons a minute or more be registered with the State Land Commissioner. This act further required that well owners or operators report every year the total amount of water produced from each of the wells registered. Up to November 1946, 700 wells in the Salt River Valley had been registered with the State Land Commissioner. Records were obtained by the Geological Survey for 137 additional wells, making a total of 837 irrigation wells for which data are available. Of this number, 638 wells were owned by irrigation districts or other large users of ground water and 199 were privately operated. Descriptions of typical wells are given in table 5. The investment in wells and pumping equipment in this area is estimated to be at least 10 million dollars. The locations of all the irrigation wells are shown on plate 1. Plate 1 also shows the areas irrigated in 1946, divided into: (1) Lands irrigated primarily with surface water, and (2) lands irrigated primarily with ground water. During 1946 a total of approximately 257,000 acres was irrigated primarily with surface water and 179,000 acres primarily with ground water. Table 3 shows the estimated quantities of ground water pumped in the Salt River Valley during the years 1933-1945, inclusive, and the quantities of surface water diverted at Granite Reef Dam. The total pumpage of ground water in 1945 was about 1,143,000 acre-feet.

Since 1920 the trend of the water table has been downward, although monor rises of the water table have occurred during or following years of high precipitation. In some areas the decline of the water table in response to heavy pumping has necessitated changes in the adjustment or "setting" of the pump bowls or speeding up the pump in order to continue delivery of sufficient water for irrigation. These changes have often resulted in overloading of the pump motors. Measurements of demand on electrically-powered installations showed that slightly more than half of those visited during this investigation were overloaded. The maximum overload was 37 percent and the average was about 16 percent. The continued downward trend of the water table indicates that the annual safe yield has been exceeded for several years and that, if pumping in the future continues at the same rate as during the last 3 years, the depletion of ground-water storage will become serious.

Natural discharge

Surface flow

The average annual discharge of surface water in the Gila River at Gillespie Dam was about 93,000 acre-feet for the period 1942-1945, inclusive[20]. Effluent seepage from the ground-water reservoir probably furnished the greater part of this flow, and the remainder was derived from floods.

Underflow

Underflow from the Salt River Valley probably occurs along the Gila River channel at Gillespie Dam, and it may also occur beneath the lava flows of the Gila Bend Mountains.

Jakosky[21] made an investigation to determine the distribution and structural relations of the geologic formations at Gillespie Dam, and their effect on the subsurface flow of water. Jakosky's investigation established the fact that aquifers exist underneath the volcanic rock on which the foundation of the dam rests, and that underflow escapes beneath the dam through these aquifers. Jakosky apparently did not estimate the quantity of underflow beneath the dam, and without additional information this cannot be computed. However, the underflow is undoubtedly small compared with the surface flow at the dam.

Underflow may follow the old courses of the Gila River through or under the lava flows of the Gila Bend Mountains. Ross[22] discusses the probability that the Gila River at one time continued its westerly course from the Salt River Valley through the area now occupied by the lava flows of the Gila Bend Mountains. He states:

> "It is probable that when Gila River was dammed by the lava flow at the Peoria dam site a large part of the water escaped westward through the pass now utilized by the old road through the Gila Bend Mountains. During this period the river did not make the long swing to the south around these mountains as it does now and as it did before the lava blocked it. Such a hypothesis seems to offer the only probable explanation of the remarkable terraces 20 to 50 feet high and a quarter of a mile to 1 mile apart along the wash that issues from the pass containing the old road on the southwest side of the mountains. The present wash is entirely inadequate to have cut such terraces."

The Peoria damsite mentioned is now occupied by Gillespie Dam.

Although the total underflow out of the Salt River Valley is unknown, the amount may be substantial and should be thoroughly investigated.

Evaporation and transpiration

The water used by plants and evaporated from the land surface constitutes the greatest part of the discharge from the Salt River Valley.

20/ Parker, G. L., and others, Surface water supply of the United States, Part 9, Colorado River Basin: U. S. Geol. Survey Water-Supply Papers 959, p. 300, 1943; 979, p. 307, 1944; 1009, p. 310, 1945; 1039 (in preparation).

21/ Jakosky, J. J., Exploration geophysics, Times Mirror Press, pp. 373-374, 1940.

22/ Ross, C. P., The lower Gila region, Ariz.: U. S. Geol. Survey Water-Supply Paper 498, p. 71, 1923.

Of this, the amount used by commercial crops is beneficial, but the amount used by the natural river-bottom growth represents an absolute waste of water.

The use of water by phreatophytes (salt cedar and other natural river-bottom vegetation) in the Salt River Valley has never been determined. The following estimate of the amount of water used by this type of vegetation in the Salt River Valley is based upon areas and densities of growth estimated from aerial photographs, and upon rates of water use by salt cedars in Safford Valley, along the upper Gila River. The aerial photographs used were made in 1941 for the Maricopa County Board of Supervisors. The total area occupied by phreatophytes along the Salt River from Granite Reef Dam to its confluence with the Gila River, and along the Gila River from this point to Gillespie Dam, was estimated from the photographs to be about 18,500 acres. About 13,500 acres of this was estimated to have a density of growth of 100 percent (maximum density). The remaining 5,000 acres was estimated to have a density of growth of 50 percent, which would be equivalent to 2,500 acres at 100 percent. The amount of water used by these plants was estimated to be about 8 acre-feet per year per acre of 100 percent density, on the basis of the Safford experiments[23/ 24/]. From these data, the total amount of water used within the Salt River Valley by this type of plant was estimated to be about 130,000 acre-feet in 1941. Since 1941 the area of growth has increased greatly.

The amount of water used by phreatophytes along the Gila River from Sacaton Dam to the gaging station near Laveen was estimated by Turner and others[25/] to be about 100,000 to 150,000 acre-feet in 1940. The area occupied by phreatophytes in the 13 miles between the gaging station near Laveen and the confluence of the Gila and Salt Rivers was not estimated, but it is known to be large.

Detailed field surveys and recent aerial photographs would be necessary for closer estimates of the total amount of water used by phreatophytes in the valleys of the Salt and Gila Rivers in the region. However, on the basis of available data, it is estimated that the water used by phreatophytes in this region is not less than 200,000 acre-feet and may be as much as 350,000 acre-feet per year.

Fluctuations of the water table

Measurements of depth to and fluctuations of the water table are of primary importance in the study of ground-water resources. The alluvial fill of the Salt River Valley is a natural underground reservoir. The water levels in wells show the extent of depletion and replenishment of this natural reservoir

Most of the available data regarding water-level fluctuations have been obtained by personnel of the irrigation districts and are confined for the most part within the project boundaries. Some of the districts,

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23/ Turner, S. F., and others, Water resources of Safford and Duncan-Virden Valleys, Ariz., and N. Mex.: U. S. Geol. Survey (mimeographed), pp. 7-10, 1941.

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

25/ Turner, S. F., and others, Ground-water resources of the Santa Cruz Basin, Ariz.: U. S. Geol. Survey (mimeographed), p. 68, 1943.

notably that of the Salt River Valley Water Users' Association, have kept good records for many years. These records were relied upon to furnish most of the history of water-level fluctuations in the Salt River Valley prior to about 1939. Since that time most districts have obtained records, but there has not been a coordinated and integrated program. During the present investigation, measurements of water levels have been made periodically in wells that were carefully selected with regard to depth, type of well, location within the valley, and length of previous record. These periodic measurements should be continued. Short-period records of water-level fluctuations have little value in the determination of changes in storage because of the large seasonal fluctuations resulting from heavy pumping.

The average ground-water level in the Salt River Project, as indicated by measurements made by the Salt River Valley Water Users' Association, showed an almost continuous rise until about 1920, when pumping and natural discharge became greater than the recharge and the water level began to decline. This downward trend has continued to the present (1946). Although conclusive data are not available, a similar downward trend probably exists in the remainder of the Salt River Valley with the exception of parts of the Roosevelt and the Buckeye irrigation districts.

In the large area occupied by the Salt River Valley, many different local factors affect the fluctuations of the water table. Therefore, the valley has been arbitrarily divided into portions that are discussed individually.

Queen Creek area and Roosevelt Water Conservation District

The water table in the Queen Creek area and in the Roosevelt Water Conservation District has declined steadily since 1930, the first year for which records are available. The average decline during the period 1930-1946, inclusive, was about 30 feet, although the maximum was 50 feet. The depth to water in most of the area was between 90 and 150 feet in 1945. The graph of well 101 (fig. 1), which is about 3 miles from the nearest irrigation well, shows a decline of the water level of about 7 feet since 1940.

Deer Valley

Development of ground water in Deer Valley for irrigation was started about 1940 and has grown steadily. The first water-level measurements available were those made about 1940, and these showed an average depth to water of about 100 feet. The graph of well 2551 (fig. 2) shows that the water level has declined 35 feet since 1942, or about 7 feet a year. This well is about a mile from the nearest irrigation well and probably shows only the general effects of pumping in Deer Valley.

Agua Fria and New River area

In 1930 the water table in the area near the junction of the Agua Fria with the Gila River and for about 2 miles to the north was less than 10 feet below the surface. The depth to water was increasingly greater to the north, and near the junction of the Agua Fria and New Rivers it was about 30 feet. Farther north, in the vicinity of Marinette, it was slightly more than 70 feet. In 1945 the depth to water remained less than 10 feet in the area near the junction of the Agua Fria and Gila Rivers but farther north, near the junction of the Agua Fria and New Rivers, the depth to water had declined to about 65 feet, and near Marinette it was 115 feet.

Typical fluctuations of the water level in the area since 1930 are shown in figure 2 (well 2852, 1½ miles northeast of Marinette). The water level in this well has declined 35 feet in 17 years.

Litchfield Park-Beardsley area

In 1930 the depth to water in the Litchfield Park area was about 50 or 60 feet and by 1945 this had increased to about 90 feet. The graph of well 3487 (fig. 3), located 2 miles west of Litchfield Park, shows typical fluctuations of the water table in this area. The trend of the water table has been downward since 1933, except for a rise during the wet winter of 1940-1941. The water table declined from 75 feet below the surface in 1930 to 103 feet in 1946. At well 3686 the first measurement available was made in 1938, at which time the depth to the water table was about 180 feet (fig. 3). Although this well is more than a mile from the nearest irrigation well, the general decline in the water level shows the effect of heavy pumping. The effect of the recharge during the wet winter of 1940-1941 did not become evident in this well until almost a year later, and then the water level continued to rise for about a year before resuming the downward trend.

Salt River Project

In 1913 the water table was less than 10 feet below the land surface in approximately 12 percent of the area occupied by the Salt River Project, according to data furnished by the Salt River Valley Water Users' Association. In about 67 percent of the project area the water table was from 10 to 50 feet below the land surface and in about 21 percent of the area the depth was from 50 to 150 feet (pl. 2). The water table in 1945 was less than 10 feet below the land surface in only 0.2 percent of the area, from 10 to 50 feet in about 55 percent of the area, and from 50 to 150 feet in about 45 percent of the area (pl. 3). The depth to water was still less than 150 feet in the Salt River Project area. Similar data for the various parts of the Salt River Valley are shown for the years 1930 and 1945 in table 2. For the Salt River Project these data are shown for the years 1913, 1920, 1930, 1940, and 1945.

In general, the water table in the Salt River Project rose from 1913 to 1920 and then started the decline that has continued to the present time.

The graph of well 1106 (fig. 1), about 2 miles east of Mesa, indicates that the water table fluctuates in response to pumping and to recharge from water used for irrigation. The water level in this well rose about 30 feet during 1941 because of reduced pumping and increased recharge. Then the water level declined and, in 1946, it reached a point about 2 feet below the previous low water level of 1940. The graph of well 1456 (fig. 1), 6 miles south of Tempe, indicates the same general type of fluctuation but there is less pumping and more recharge from water used for irrigation than in the vicinity of well 1106.

The water level rose almost 25 feet during 1941 and 1942 in well 1603 (fig. 1) at Scottsdale, which is in an area of moderately heavy pumping. It has shown a net decline of about 16 feet since 1935. Well 3051 (fig. 2) is in an area of heavy pumping near Tolleson and the graph shows a decline in water level of almost 31 feet since 1930. This area receives a large amount of recharge from water used for irrigation to the north and east.

Roosevelt Irrigation District

A part of the Roosevelt Irrigation District occupies the area where the valley fill narrows between the White Tank Mountains on the north and the Buckeye Hills on the south. This constriction forces a part of the underflow in the valley to the surface in the low areas along the Gila River. In both 1930 and 1945 no appreciable part of the Roosevelt Irrigation District had a depth to water of less than 10 feet. The area in which the water table was 50 to 150 feet below the surface decreased from about 66 percent in 1930 to 57 percent in 1945 (see table 2). The graph of well 4051 (fig. 3), 1 mile southwest of Perryville, shows the effect of wet and dry cycles with no definite long-time trend. The graph of well 4711 (fig. 3), about 2 miles north of Hassayampa, also shows minor fluctuations but has a general upward trend, which amounted to about 10 feet during the period 1938-1945, inclusive.

Buckeye Irrigation District

The quantity of water pumped for irrigation and drainage in the Buckeye Irrigation District is small when compared with the quantity of surface water diverted. A part of the district lies in the area where the valley fill narrows between the White Tank Mountains on the north and the Buckeye Hills on the south. This constriction forces a part of the underflow to the surface in the low areas along the Gila River.

Table 2 shows that in 1930 the water table was less than 10 feet below the surface in approximately 57 percent of the area within the district (including the flood plain of the Gila River), and that by 1945 this area had decreased to about 44 percent. The remainder of the area in both 1930 and 1945 had a depth to water of 10 to 50 feet. Available records of water-level measurements in this area were insufficient for the preparation of graphs.

Safe yield of the ground-water reservoir

Perhaps the most vital concern of farmers in the Salt River Valley is the determination of the quantity of water that can be pumped annually from the ground-water reservoir without depleting the supply available for continued economical pumping. The downward trend of the water levels during the last several years indicates that, under existing conditions, the annual safe yield has been exceeded. The safe yield is affected by many factors that cannot be evaluated with existing data and, therefore, no estimate of the annual safe yield is given in this report. The average annual recharge from all sources must be determined. The total discharge, including both surface flow and underflow leaving the valley and the quantity of water used by salt cedars and other river-bottom growth, must be measured. The quantities of soluble salts entering and leaving the valley must be known. Consideration must be given to the necessity of bringing these quantities more nearly into balance, as discussed in the ensuing section on quality of water. The relation of this "salt balance" to the annual safe yield of the ground-water reservoir must be considered. In this connection, the possibility of preventing some of the salt inflow to the upper Salt River should be thoroughly investigated.

QUALITY OF WATER

Chemical character of the ground water

More than 500 analyses of ground water from the Salt River Valley were used in the preparation of this report. Some of these analyses were obtained from the Salt River Valley Water Users' Association. The Geological Survey collected and analyzed about 150 samples from all parts of the region between 1940 and 1946.

Plate 4 was prepared from all the available analyses, and this map shows the concentration of dissolved solids in ground waters in most of the area. Ground waters of the area differ considerably in concentration. In the eastern and northern parts of the area the ground waters generally contain less than 1,000 parts per million of dissolved solids. Plate 4 shows that most ground waters containing more than 3,000 parts per million of dissolved solids are found in the following localities: (1) South of Chandler, (2) along the southern edge of the Salt River Mountains, (3) west of Laveen, (4) along the Salt River between Phoenix and the confluence of the Salt and Gila Rivers, and (5) along the Gila River from its confluence with the Salt River to Gillespie Dam.

Analyses for typical ground waters in the area are shown in table 6. These analyses show that the less highly-mineralized waters usually contain mainly calcium, magnesium, chloride, and bicarbonate. The more highly-mineralized waters generally contain mostly sodium and chloride, and the most highly-mineralized waters contain large amounts of calcium and sulfate in addition. Abnormally high proportions of some of the minor constituents are present in certain waters of the area. In most of the ground waters of the United States nitrate is present in very small quantities, generally less than 1 part per million. In ground waters of the Salt River Valley, nitrate concentrations of 50 to 100 parts per million are common. In many places in the area fluoride is present in quantities greater than 1.5 parts per million[26/]. Borate was found in some of the waters of the area, and the highest concentration of borate found was 40 parts per million in well 1457 (table 6). No other comparably high concentrations of borate were found, but a few samples from wells in the eastern part of the area contained as much as 4.0 parts per million. Less than 1 part per million of borate was found in most samples.

Chemical character of surface waters

Many analyses are available for the waters of the Salt and Verde Rivers in the area. A few analyses are available for the Gila River at the Ashurst-Hayden Dam[27/], and many more are available for this river near its confluence with the Salt River and at Gillespie Dam. Only a few analyses for the other streams are available.

Water of the Salt River a few miles upstream from its confluence with the Verde River is of moderate to moderately high concentration, usually

26/ Smith, H. V., Smith, M. C., and Foster, E. O., Mottled enamel in the Salt River valley and the fluorine content of the water supplies: Univ. Ariz., Coll. Agr., Agr. Exp. Sta. Tech. Bull. 61, pp. 390-418, 1936.

27/ Collins, W. D., Howard, C. S., and Love, S. K., Quality of surface waters in the United States, 1941: U. S. Geol. Survey Water-Supply Paper 942, p. 65, 1942.

containing mostly sodium and chloride. Water of the Verde River is usually lower in concentration than that of the Salt River, containing mostly calcium and bicarbonate. In the 12 months ending September 30, 1945, the minimum concentration of dissolved solids in the combined flow of the Salt and Verde Rivers at Granite Reef Dam was 226 parts per million, and the maximum was 601 parts per million. From the small amount of data available, waters of the Gila River entering the area at Ashurst-Hayden Dam seem to have about the same average concentration of dissolved solids as the waters of the Salt River a few miles upstream from its confluence with the Verde River. However, the Gila River waters contain proportionately more calcium and sulfate and less sodium and chloride than do the waters of the Salt River. It is probable that surface runoff in the other streams entering the area is of rather low mineral content, although little is known of the chemical character of these waters.

Surface flows in the Salt and Gila Rivers near their confluence are derived mostly from seepage of highly-mineralized ground waters. These seepage waters contain mostly sodium and chloride but also have high concentrations of calcium, magnesium, and sulfate. During nearly all of the 12 months ending September 30, 1945, the concentration of dissolved solids in the water of the Gila River at Gillespie Dam varied less than 10 percent from an average concentration of about 4,000 parts per million. For a short period during August 1945, flood waters reached the dam and diluted the normal drainage waters considerably. Flood waters in this region are generally low in dissolved matter. However, mixing of flood waters with more highly-mineralized low-flow waters in storage reservoirs on the Salt, Verde, and Gila Rivers tends to modify the extremes in concentration that are typical of uncontrolled flows in these streams.

Table 7 contains three representative analyses of surface waters in the area. The approximate average concentration of the mixed Salt and Verde River waters diverted into the Arizona Canal at Granite Reef Dam during the 12 months ending September 30, 1945, is shown by analysis 1, and the approximate average concentration of these waters diverted into the South Canal at this point during the period is shown by analysis 2. The approximate average composition of water leaving the Salt River Valley as surface flow in the Gila River at Gillespie Dam during the same period is shown by analysis 3.

Relation of quality of water to use

Irrigation

In the Salt River Valley large quantities of water are used for irrigation. A large part of this water is obtained from surface sources, principally from the Salt and Verde Rivers. Water from these streams at Granite Reef Dam is generally "excellent to good"28/ for irrigation use, but at times the water diverted at Granite Reef Dam may be sufficiently high in sodium percentage to be classified as "good to injurious".

Drainage waters that return to the river channels within the area are diverted and reused for irrigation in the western parts of the Salt River Valley, or in the Gila Bend area south of Gillespie Dam. These

28/ Wilcox, L. V., and Magistad, O. C., Interpretation of analyses of irrigation waters and the relative tolerance of plant crops: U. S. Dept. Agr., Bur. Plant Industry, Soil and Agr. Research Administration; Riverside, Calif. Mimeographed, 8 pp., May 1943.

waters are usually within the "injurious to unsatisfactory" classification, but occasionally flood flows dilute the drainage waters and improve their quality.

Ground waters in the eastern and northern parts of the Salt River Valley are generally "excellent to good" for irrigation, but plate 4 shows that the ground waters are highly mineralized in a large part of the Salt River Valley. These highly-mineralized waters would generally be classed as "injurious to unsatisfactory" for irrigation.

Domestic use

The public water supply for Phoenix is obtained from a system of wells and an infiltration gallery along the Verde River. Water from this system is hard but does not contain an excessive amount of dissolved matter. Additional water is obtained from wells near Scottsdale. Water from these wells is hard and rather highly mineralized. The public water supplies of smaller towns and private domestic supplies in rural areas are generally obtained from wells. In many places these waters are excessively hard and may contain sufficient amounts of sodium and chloride or other substances to have an unpleasant taste. Ground water in much of the area may contain sufficient fluoride to cause permanent mottling of the tooth enamel when drunk continuously by small children.

Industrial use

Because of the growth of the city of Phoenix and the expansion of local industries, an increasing amount of water is used industrially in the area. An important and rapidly increasing use of water is for the air-conditioning of buildings. Water that is available to wells in the vicinity of Phoenix is of satisfactory quality for cooling; however, this water is not chemically suited for many industrial requirements without softening or other treatment.

Relation of quality of water to recharge and source of dissolved solids in ground water

In the irrigated portion of the Salt River Valley the principal sources of ground-water recharge are those associated with irrigation. Irrigation water applied is partially evaporated and transpired. The dissolved matter originally contained in this part of the water is left behind in the soil and later is carried down to the ground-water reservoir by the infiltration of excess irrigation water, and the effect of this type of recharge is shown in the rather high mineralization of ground waters in most of the irrigated parts of the area. In the zones of high dissolved-solids concentration near Chandler and in the western part of the area the mineralization is caused partly by downward seepage of irrigation water that has become highly-mineralized in this way. It is likely that in these areas the movement of ground water is slow, and the pumping and re-pumping of ground water for irrigation has caused the accumulation of highly-mineralized water. Also, it is possible that mineral matter may be contributed to the ground water in the area near Chandler from soluble deposits laid down under local playa conditions when the valley fill was being formed. The extent to which upward leakage of artesian water may contribute mineral matter to the fill is not known.

Waters of low mineral content are added to the ground-water reservoir by flood flows in the streams of the area and, perhaps in a few places, directly by rainfall. The ground water in the Queen Creek area is recharged mainly by flood flows. Waters in this part of the area, as shown by plate 4, are of comparatively low mineral content. They tend normally to move westward, but ground-water movements in the entire area are influenced considerably by pumping. Recharge from flood flows in washes also reaches the Salt River Valley along the north side of the area. The amount of this recharge is apparently small because most of the areas with water of low mineral content along the north side of the Salt River Valley are small. An exception occurs in the vicinity of the Agua Fria and New Rivers. In this locality recharge from these streams causes considerable dilution of the ground water. The effect of this recharge is sufficient to cause wide differences in the concentration of ground water in closely-spaced wells west of Tolleson. Farther south, near the Gila River, however, the effect of this recharge is no longer apparent, probably because most of the diluted water is removed by pumping before it reaches this area.

The only locality within the Salt River Valley where recharge from deep-seated inflow is definitely known to occur is east of Mesa. Several wells in this locality yield hot water with a somewhat higher dissolved-solids content than that of water of normal temperature from surrounding wells. The amount of recharge from this inflow cannot be closely estimated but it probably is rather large because the temperature and the quality of water are affected in an area of at least 5 square miles (pl. 4). The warmest water in this area comes from a well at the Buckhorn resort 7 miles east of Mesa, and has a temperature of 112° F.

Sources of dissolved matter in surface waters entering the area

Surface waters of the upper Salt and Gila Rivers are often rather highly mineralized. Some of the sources of the dissolved matter in these streams have been located by previous investigators. Hayden[29/] has summarized the available information regarding salt inflows that reach the Salt River upstream from Roosevelt Dam. The quantity of salt entering the stream in a 20-mile reach of the river, in the vicinity of Carrizo Creek, is stated in Hayden's report to be about 315,000 tons annually. This amount is derived from salt springs and from leaching of salt deposits in the area, both along Carrizo Creek and along the Salt River downstream from the mouth of the creek.

The sources of dissolved matter in Gila River waters are not localized. Much dissolved matter is added to the stream by salt spring inflows, artesian leakage, and drainage from irrigated lands east of Coolidge Dam, and additional dissolved matter is brought in west of the dam by springs and by inflow from tributary streams.

Discharge of dissolved salts from the Salt River Valley

If accumulation of soluble matter within the region, in either the soil or the ground-water reservoir, is to be prevented, the soluble matter removed from the region by drainage must approximately equal the soluble matter entering the region from all sources. The principal means by which dissolved solids are discharged from the region is in the water draining out as surface flow in the Gila River at Gillespie Dam. In addition, an unknown but probably much smaller quantity of dissolved solids is removed from the region by underflow.

The Salt, Verde, and Gila Rivers are the three main sources of the soluble matter entering the region. Minor amounts are brought in by other streams and by inflow from deep-seated sources.

It is not possible to determine accurately the total amount of soluble

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29/

Hayden, T. A., Salt investigations on Upper Salt River: Manuscript report for Salt River Valley Water Users' Association, 4 pp., 3 pl., 1940.

matter that is annually brought into the basin. Fairly complete data are available for computing the inflow of dissolved matter in the Salt and Verde Rivers and the outflow of dissolved matter in the Gila River at Gillespie Dam. These data were obtained from the files of the Salt River Valley Water Users' Association. The amounts of soluble matter brought in by the waters of the Gila River and other streams cannot be computed because few chemical analyses for these waters are available.

The available data are not adequate for determination of the balance between salt inflow and outflow. However, there are ample indications that soluble salts are accumulating in parts of the Salt River Valley. From water analyses and discharge records it is estimated that, in the 12 months ending September 30, 1945, about 600,000 tons of dissolved solids entered the valley in the surface flow of the Salt and Verde Rivers. The amount contributed by the Gila River during the period cannot be computed from the available data, but it was undoubtedly large. In the same period about 460,000 tons was removed from the valley in the surface flow of the Gila River past Gillespie Dam. Some additional soluble matter is removed from the valley by underflow. The amount thus removed is unknown, and although it probably is comparatively small it is significant and further studies must be made before the total quantity of soluble matter leaving the valley can be closely determined.

From these figures, it is apparent that the amount of dissolved matter removed from the valley in the surface flow of the Gila River past Gillespie Dam during the period was at least 140,000 tons less than the amount of dissolved matter brought into the valley by the Salt and Verde Rivers alone. This 140,000 tons of soluble matter must have been left in the valley. In addition, an amount equal to the soluble matter contributed by the Gila River and all other sources was left in the valley during the period, except for an unknown but probably minor amount removed by underflow.

Many wells in the valley have been sampled several times since about 1937. The analyses of these samples show the changes that are taking place in the quality of ground water in the area. Where the ground waters are of moderate mineral content, as in the eastern part of the Salt River Project, the concentrations have decreased slightly in some places but have increased slightly in others in the 10 years of record. These changes probably have resulted from the movement of ground water through the area. Further sampling and continued records of pumpage in the area are needed to show the influence pumping may have upon these ground-water movements and the resulting changes in the quality of the water.

Soluble salts are probably accumulating in at least two of the areas shown by plate 4 to be underlain by water with more than 3,000 parts per million of dissolved solids. In 1946 many wells in the area southwest of Chandler yielded water that was more highly mineralized than that yielded in 1941. That salt is accumulating in the western end of the Salt River Valley is indicated by records of analyses for some of the wells of the Roosevelt Irrigation District near Buckeye. Water from some of the wells in this area has doubled in the concentration of dissolved solids since 1937, and a few of the wells have been abandoned because of the increase in mineral content. This area has some of the most highly-mineralized ground waters of the Salt River Valley (see pl. 4).

If the present trend continues, the increase in mineral content of ground water in the vicinity of Buckeye will eventually force a reduction in the amount of water pumped for irrigation as more of the water becomes too highly mineralized to be used. This reduction in pumpage would increase the flow of dissolved solids out of the area at Gillespie Dam, as the water table would rise and more ground water would move into the river channel. This would tend to bring salt outflow and inflow more nearly into balance.

It may be possible to bring the outflow and inflow of dissolved salts in the valley more nearly into balance by reducing the salt inflow. It has been shown that a total of about 315,000 tons of salts enters the Salt River annually east of Roosevelt Dam. It might be feasible to prevent some of this salt inflow. However, even if all or a substantial part of this salt inflow could be stopped it is unlikely that a satisfactory "salt balance" could be maintained with an annual outflow of dissolved salts less than the 450,000 tons that left the area in the 12 months ended September 30, 1945. Further increases in pumping in the area will reduce the quantities of water passing Gillespie Dam and hence will tend to reduce the total amount of soluble salts annually removed from the area.

The large amount of water transpired by the dense growths of salt cedar and other river-bottom vegetation increases the concentration of dissolved solids in the river-bottom area because the dissolved matter in the water is left behind when the water is transpired. If this waste of water could be stopped the ground water in this part of the valley would be of better quality. Seepage of this more dilute water into the river channels would increase the quantity and improve the quality of the waters of the Salt and Gila Rivers in the area where these streams are effluent.

SUMMARY AND CONCLUSIONS

The area included in this investigation is generally known as the Salt River Valley. It lies principally in Maricopa County, although a part along the south and east margins lies in Pinal County. The area is a part of the broad, flat plain that occupies a large portion of southern Arizona.

Ground water occurs in the gravel and sand deposits in the unconsolidated sediments in the Salt River Valley. These sediments were derived from the broken, mountainous country to the north and east and from the isolated ranges within the valley borders. The sand and gravel deposits are the source of water for most of the wells in the area. The beds are discontinuous but interconnected, as in any given locality the water in practically all wells stands at a definite level that forms a comparatively uniform surface.

Water recharged to the aquifers in the region is derived from four main sources, listed in order of importance: (1) Irrigation and canal seepage, (2) stream flow, (3) underflow of major streams that enter the region, and (4) rainfall. The total recharge to the ground-water reservoir cannot be estimated because sufficient data are not available.

Discharge of ground water in the Salt River Valley occurs both by pumping and by natural means. Natural discharge includes ground water that enters the streams and is discharged as surface flow; it also includes underflow out of the valley, and water discharged by evaporation and transpiration. Pumping in any part of the valley affects the ground-water supply of the valley by increasing the amount evaporated and transpired and reducing that discharged as surface flow and underflow.

Records were obtained for a total of 837 irrigation wells in the Salt River Valley during this investigation, and the investment in wells and pumping equipment is estimated to be at least 10 million dollars. In 1946 approximately 257,000 acres was irrigated primarily with surface water and 179,000 acres primarily with ground water. The total pumpage of ground water in 1945 was about 1,143,000 acre feet. The average annual discharge of surface water in the Gila River at Gillespie Dam was about 93,000 acre-feet during the period 1942-1945, inclusive. Effluent seepage from the ground-water reservoir probably furnished the greater part of this flow. The quantity of underflow out of the Salt River Valley is unknown, but the amount may be significant and should be thoroughly investigated. The water used by plants and the water evaporated from the land surface constitutes the greatest part of the discharge from the Salt River Valley. Of this, the amount used by commercial crops is beneficial, but the amount used by natural river-bottom growth represents an absolute waste of water. The quantity of water used by salt cedar and other natural river-bottom vegetation in the Salt River Valley has not been determined, but it is estimated to be not less than 200,000 acre-feet and may be as much as 350,000 acre-feet per year.

The alluvial fill of the Salt River Valley is a natural underground reservoir. Measurements of water levels in wells show the extent of depletion and replenishment of this reservoir. The average water level in the Salt River Project showed an almost continuous rise until about 1920, largely as a result of irrigation. Since 1920 the trend of the water table has been downward, although during or following years of high precipitation minor rises of the water table have occurred. In the Queen Creek area and in the Roosevelt Water Conservation District the water table has declined an average of about 30 feet since 1930. Development of ground water for irrigation in Deer Valley started about 1940, and measurements indicate that the water level has declined about 35 feet since 1942. The water level in the Agua Fria and New River areas has declined an average of about 35 feet since 1930. In the Litchfield Park-Beardsley area the water level has declined an average of about 30 feet since 1930. Parts of the Roosevelt and Buckeye irrigation districts lie in the narrows between the White Tank Mountains on the north and the Buckeye Hills on the south. This constriction forces a part of the underflow to the surface in the low areas along the Gila River. In parts of these districts the water levels have risen about 10 feet since 1938.

The annual safe yield of the ground-water reservoir in the Salt River Valley cannot be estimated with existing data, but the downward trend of the water levels during the last several years indicates that, under existing conditions, the annual safe yield has been exceeded.

The more dilute ground waters, which are in the north and east parts of the Salt River Valley, contain mainly calcium and bicarbonate. The more highly-mineralized waters, which are in the central and western parts of the valley, contain mostly sodium and chloride. Waters of the Salt River at Granite Reef Dam and of the Gila River at Ashurst-Hayden Dam have moderate concentrations of dissolved solids and contain mostly sodium and chloride. Surface waters of streams entering the valley are usually "excellent to good" for irrigation. The more highly-mineralized ground waters and the low-flow waters of the Gila River below its junction with the Salt River are generally "injurious to unsatisfactory". The high mineralization of ground waters in some parts of the area probably is due to recharge by irrigation water and to leaching of salts from playa deposits in the valley fill.

Previous investigators report that a total of 315,000 tons of salts reaches the Salt River annually in the stretch upstream from Roosevelt Dam. The Salt and Verde Rivers carried about 600,000 tons of soluble salts into the valley in the 12 months ending September 30, 1945, and large additional amounts of soluble matter entered the valley in the surface flow of the Gila River. In this period 460,000 tons was carried from the valley in surface flow past Gillespie Dam, and some soluble salts were removed from the valley by underflow. The quantity removed by underflow probably was comparatively small. These figures indicate that soluble salts are accumulating in the valley. The concentration of dissolved matter in most of the ground water at the west end of the valley has increased greatly since 1937, and some of the water has become too highly mineralized to be used for irrigation.

The quality of water in the Salt and Gila Rivers, in the area where they are effluent, probably would be improved by removal of the river-bottom growth.

Table 1. Summary of climatological data, 1896-1944, Phoenix, Maricopa County, Arizona.
(From records of U. S. Weather Bureau)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Annual
Mean max. temp., °F.	65.1	68.9	74.6	82.4	91.1	101.1	103.5	101.4	97.2	86.4	74.8	65.7	84.4
Mean min. temp., °F.	38.9	42.7	47.0	53.0	60.3	69.2	77.2	76.0	69.2	56.3	45.4	39.6	56.2
Mean temp., °F.	52.0	55.7	60.8	67.7	75.7	85.1	90.4	88.7	83.2	71.4	60.1	52.6	70.3
Extreme max. temp., °F.	84	92	95	103	114	118	118	115	112	105	96	84	118
Extreme min. temp., °F.	16	24	30	35	39	49	63	58	49	36	27	22	16
Mean precipitation, in.	0.80	0.86	0.71	0.43	0.13	0.07	1.02	0.98	0.88	0.44	0.68	0.94	7.94
Greatest monthly precip., in.	3.67	4.64	4.82	3.36	1.31	0.75	6.47	4.92	5.4[illegible]	2.30	.61	3.75	19.73
Year of occurrence	1897	1905	1941	1926	1930	1899	1911	1943	1939	1914	1905	1940	1904

Table 2. Area underlain by water table at different depths, by districts, 1913-1945, Salt River Valley
(Expressed as percentage of total area within each district)

District	Buckeye Irr. Dist.		Goodyear Farms, Marionette Farms, MCMWCD. a/		Queen Creek area and Chandler Heights		Roosevelt Irr. Dist.		Roosevelt Water Cons. Dist.		Salt River Project					Salt Rive[illegible] Valley a[illegible]	
Year	1930	1945	1930	1945	1930	1945	1930	1945	1930	1945	1913	1920	1930	1940	1945	1930	1[illegible]
Depth to water table (feet)																	
0-10	57	44	0	0	0	0	0	0	0	0	12	31	0.3	0	0.2	2.5	[illegible]
10-50	43	56	5	2	0	0	34	43	14.6	12	67	65	69	60	55	48.3	3[illegible]
50-150	0	0	58	51	95	32	66	57	85	72	21	4	30.7	40	44.8	44.0	4[illegible]
over 150	0	0	37	47	5	68	0	0	0.4	16	0	0	0	0	0	5.2	1[illegible]

a/ Combined areas of Goodyear Farms, Marionette Farms, and Maricopa County Municipal Water Conservation District.

Table 3. Quantity of surface water diverted at Granite Reef Dam and quantity of water pumped from wells, 1933-1945, Salt River Valley, Pinal and Maricopa Counties, Arizona
(Acre-feet)

	1933	1934	1935	1936	1937	1938	1939
Water pumped from wells	572,000	711,000	554,000	684,000	665,000	905,000	738,000
Water diverted at Granite Reef Dam	936,700	841,800	1,043,000	1,073,300	1,277,900	1,067,800	777,000
Percentage ratio, water pumped to water diverted at Granite Reef Dam	61.1	84.5	53.1	63.7	52.0	84.8	95.0

	1940	1941	1942	1943	1944	1945
Water pumped from wells	943,000	444,000	1,004,000	1,104,000	1,017,000	1,143,000
Water diverted at Granite Reef Dam	603,800	1,249,400	1,104,800	981,400	991,100	997,900
Percentage ratio, water pumped to water diverted at Granite Reef Dam	156.1	35.5	90.8	112.5	102.6	114.5

Table 4. Logs of typical wells in Salt River Valley, Maricopa County, Arizona

Driller's log of well 14

Roosevelt Water Conservation District, owner. $NW\frac{1}{4}SW\frac{1}{4}$ sec. 23, T. 1 N., R. 6 E.

	Thickness (feet)	Depth (feet)
Topsoil	8	8
Caliche clay	64	72
Tight gravel and boulders	84	156
Loose sand and gravel	32	188
Caliche	13	201
Loose sand and gravel	18	219
Caliche	5	224
Loose sand and gravel	4	228
Cement	4	232
Loose sand and gravel	6	238
Alternate loose strata and cemented loose gravel	18	256
Cement	23	279
Very loose gravel	73	352
Very hard cemented gravel	12	364
Caliche	131	495
Very hard cemented gravel	11	506
Caliche	6	512
Very coarse gravel mixed with hard streaks	183	695
Loose sand and gravel	9	704
Gravel and cemented streaks	10	714
Very hard cemented gravel	12	726
Gravel and cemented streaks	35	761
Cemented sand and gravel	23	784
Gravel with clay streaks	6	790
Hard clay	20	810
TOTAL DEPTH		810

Driller's log of well 25

Roosevelt Water Conservation District, owner. $NW\frac{1}{4}NW\frac{1}{4}$ sec. 35, T. 1 N., R. 6 E.

	Thickness (feet)	Depth (feet)
Sandy clay	7	7
Caliche and clay	19	26
Clay	6	32
Caliche clay	52	84
Sand, gravel and boulders	8	92
Caliche shell	9	101
Cement	7	108
Sand and gravel	4	112
Caliche and gravel	3	115
Sand and gravel	3	118
Cement, caliche, and gravel	7	125
Sand and gravel	4	129
Clay and gravel	8	137
Sand and gravel	4	141
Clay, gravel and boulders	20	161
Sand and gravel	3	164
Clay, gravel and boulders	8	172
Sand and gravel	6	178
Clay and boulders	7	185
Sand and gravel	5	190
Clay and gravel	8	198
Coarse sand	10	208
Sand and gravel	9	217
Hard clay	3	220
Sand and gravel	6	226
Clay	15	241
Coarse sand	11	252
Clay	5	257
Coarse sand	11	268
Clay	22	290
Coarse sand and gravel	22	312
Clay	2	314
Coarse sand and some clay	18	332
TOTAL DEPTH		332

Table 4. Logs of typical wells in Salt River Valley, Maricopa County, Arizona-Cont.

Driller's log of well 3387

Roosevelt Irrigation District, owner. NE¼NE¼ sec. 10, T. 1 N., R. 1 E.

	Thickness (feet)	Depth (feet)
Soil	3	3
Caliche	18	20
Sand	11	29
Coarse gravel, boulders and some sand	31	60
Packsand and small gravel	30	90
Hard packsand or sandstone	10	100
Cemented gravel	15	115
River silt	10	125
Soft sandstone	12	137
Cemented sandstone	4	141
Caliche and gravel	12	153
Hard sandstone	5	158
Sand and gravel	7	165
Sand rock	4	169
Good sand, gravel and boulders	26	195
Hard sandstone	15	210
TOTAL DEPTH		210

Driller's log of well 3686

Maricopa County Municipal Water Conservation District No. 1, owner. NE¼SE¼ sec. 8, T. 4 N., R. 1 W.

	Thickness (feet)	Depth (feet)
Hard red clay	12	12
Caliche	5	17
Sandy red clay	13	30
Caliche	5	35
Brown clay	19	54
Gravel and clay	2	56
Sandy brown clay	62	118
Clay and caliche	18	136
Gravel and caliche	4	140
Caliche	14	154
Brown sandy clay	30	184
Gravel and caliche	14	198
Sandy brown clay	50	248
Caliche and gravel	12	260
Hard brown clay	10	270
Cemented gravel	10	280
Brown clay and gravel	15	295
Cemented gravel	9	304
Hard cemented sand, gravel	18	322
Sandy brown clay	2	324
Conglomerate	40	364
Sandy brown clay, cemented streaks	36	400
TOTAL DEPTH		400

Table 5. Records of typical wells in Salt River Valley, Pinal and Maricopa Counties, Arizona
(All wells are drilled.)

No.	Location: Township and Range	Location: Section	Owner	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
14	T. 1 N., R. 6 E.	NW¼SW¼ sec. 23	Roosevelt Water Cons. Dist.	-	-	810	20
25	do.	NW¼NW¼ sec. 35	do.	-	-	332	20
41	T. 2 S., R. 8 E.	NW¼SE¼ sec. 27	W. A. Barkley	-	1,558.2	-	6
68	T. 1 N., R. 7 E.	NW¼SE¼ sec. 23	Pearlstein	-	1,584.9	-	8
101	T. 1 S., R. 7 E.	NE¼SE¼ sec. 25	Gardiner	1910	1,460.2	170	6
125	T. 1 S., R. 6 E.	NW¼NW¼ sec. 12	Ralph Halliday		1,307.3	-	6
205	T. 2 S., R. 6 E.	SE¼SW¼ sec. 24	J. E. Watson	-	1,350.4	-	18
261	T. 2 S., R. 7 E.	NW¼NW¼ sec. 15	Higley Ward School	1937	1,401	220	6
d/ 851	T. 1 N., R. 6 E.	SE¼NE¼ sec. 23	T. W. Sliger	1939	-	350	6
926	T. 2 N., R. 6 E.	NW¼NW¼ sec. 31	C. H. Semon	-	1,253.8	135	6
1106	T. 1 N., R. 5 E.	NE¼SE¼ sec. 25	Charley Weaks	-	1,235.8	-	6
1206	T. 1 S., R. 5 E.	SW¼SW¼ sec. 16	-	-	1,203.2	-	-
1207	do.	NE¼NE¼ sec. 36	-	-	1,245.9	-	-
1306	T. 2 S., R. 5 E.	NE¼SE¼ sec. 6	-	-	1,193.2	-	6
1456	T. 1 S., R. 4 E.	SW¼SW¼ sec. 15	G. R. Finch	-	1,186.3	400	6
d/ 1457	do.	SW¼SW¼ sec. 29	Ben Taylor	-	-	100	6
1501	T. 1 N., R. 4 E.	NW¼NE¼ sec. 24	Elkin	-	1,181.2	-	4
d/ 1601	T. 2 N., R. 4 E.	SW¼NE¼ sec. 19	Stannards	-	1,247.0	-	-
d/ 1602	do.	NE¼NW¼ sec. 24	S.R.V.W.U.A.	1925	1,258.2	161	20
1603	do.	NW¼NW¼ sec. 26	-	-	1,248.0	-	6
1906	T. 3 N., R. 3 E.	NW¼NW¼ sec. 32	Geo. R. Putnam	-	1,229.4	91	4

a/ Measuring point was usually top of casing, top of pump base, or top of well curb.

b/ T, turbine; C, cylinder; E, electric motor; G, gasoline or natural gas; W, wind; H, hand; O, Diesel.

Well records obtained by F. I. Bluhm and J. P. Mooseau, Jr.

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Remarks
14	-	-	T,E	I	See log.
25	-	-	T,E	I	Do.
41	229.4	Aug. 30, 1946	C,W	S	-
68	306.8	Aug. 27, 1946	C,G	D	-
101	168.5	Aug. 29, 1946	C,G	S	-
125	172.7	Aug. 28, 1946	C,E	D	-
205	145.6	Aug. 29, 1946	T,E	I	-
261	159.4	do.	C,E	P	-
851	e/ 230	Mar. 1946	T,E	D,P	Used for hot mineral baths.
926	90.5	Oct. 14, 1946	C,E	D	-
1106	85.7	do.	~~C,E~~	~~D~~	-
1206	e/ 40.0	Mar. 1945	-	D	-
1207	e/ 93.4	Apr. 1946	-	D	-
1306	e/ 42.0	Mar. 1946	C,H	D	-
1456	39.8	Aug. 1, 1946	C,E	D	-
1457	68.1	Oct. 15, 1946	C,E	D,S	-
1501	28.4	do.	None	N	-
1601	12.8	Oct. 28, 1946	None	N	-
1602	e/ 83.4	Apr. 1946	T,E	I	Discharge 1,520 gallons a minute.
1603	79.9	July 25, 1946	C,H	N	-
1906	78.5	Oct. 28, 1946	None	N	-

c/ I, irrigation; S, stock; D, domestic; P, public supply; N, none.
d/ See table 6 for analysis of water from this well.
e/ Water level reported.

No.	Location: Township and Range	Location: Section	Owner	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
1956	T.2 N.,R. 3 E.	NE¼SE¼ sec. 16	L. C. Smith	-	1,158.5	-	-
2056	T.1 N.,R. 3 E.	NE¼NW¼ sec. 36	Godfrey	-	1,136.8	-	6
d/ 2156	T.2 S.,R. 3 E.	NE¼ sec. 28	Lone Butte Farm	-	-	-	-
d/ 2256	T.1 S.,R. 3 E.	NE¼NW¼ sec. 36	W. R. Collier	-	-	-	8
2301	T.1 S.,R. 2 E.	SE¼SE¼ sec. 8	A. Cheatum	-	1,035.6	-	-
2451	T.2 N.,R. 2 E.	NW¼SW¼ sec. 8	V. E. Messinger	-	1,144.6	-	6
2452	do.	SW¼SW¼ sec. 13	Leonard	-	1,140.6	49	6
2551	T.3 N.,R. 2 E.	SE¼SE¼ sec. 24	Chas. Christopher	-	1,255.7	-	-
2801	T.4 N.,R. 1 E.	NE¼NE¼ sec. 30	-	-	-	180	16
2852	T.3 N.,R. 1 E.	NW¼NE¼ sec. 9	J. G. Boswell Co.	-	1,172	248	18
2853	do.	NW¼SW¼ sec. 26	-	-	1,137.7	-	-
2854	do.	NW¼NE¼ sec. 29	J. G. Boswell Co.	-	1,122	-	18
d/ 2855	do.	NE¼SW¼ sec. 17	do.	-	-	-	-
d/ 2951	T.2 N.,R. 1 E.	SE¼SE¼ sec. 8	Ray Fram	-	1,059.2	-	-
d/ 3051	T.1 N.,R. 1 E.	NE¼SE¼ sec. 12	Roosevelt Irr. Dist.	1929	1,028.8	182	20
d/ 3052	do.	SW¼NW¼ sec. 27	S.R.V.W.U.A.	-	972.6	-	-
d/ 3386	T.1 N.,R. 1 W.	NE¼SE¼ sec. 9	Goodyear Farms	1925	982.6	218	26
d/ 3387	do.	NE¼NE¼ sec. 10	Roosevelt Irr. ~~Dist.~~	1939	987.0	210	20
3486	T.2 N.,R. 1 W.	SE¼NE¼ sec. 2	Goodyear Farms	-	-	180	20
d/ 3487	do.	NE¼NE¼ sec. 19	do.	1920	1,060	280	26
d/ 3488	do.	SE¼NW¼ sec. 12	do.	-	-	207	26
3686	T.4 N.,R. 1 W.	NE¼SE¼ sec. 8	M.C.M.W.C.D.	1938	1,339	500	20

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Remarks
1956	e/ 22.5	Oct. 1946	-	D	-
2056	e/ 32.9	do.	-	-	-
2156	e/ 30	Mar. 1946	T,O	I	Discharge 2,700 gallons a minute.
2256	85.2	Oct. 15, 1946	C,E	D	-
2301	e/ 10.9	Oct. 1946	-	D	-
2451	70.1	Oct. 29, 1946	None	N	-
2452	e/ 32.5	do.	C,H	N	-
2551	136.5	Oct. 28, 1946	None	N	-
2801	141.1	Oct. 16, 1946	None	N	Unused irrigation well.
2852	110.0	Aug. 1946	T,E	I	Discharge 700 gallons a minute.
2853	e/ 56.5	Oct. 1946	C,H	D	-
2854	e/ 94.0	Aug. 1946	T,E	I	Discharge 1,000 gallons a minute.
2855	e/ 120	Jan. 1946	T,E	I,P	Water supply for town of Marinette.
2951	61.3	Oct. 28, 1946	None	N	-
3051	e/ 50.3	Mar. 1946	T,E	I	Discharge 3,600 gallons a minute.
3052	e/ 15.1	Dec. 1945	-	-	-
3386	48.4	Oct. 16, 1946	T,E	I	Discharge 1,480 gallons a minute.
3387	e/ 40.0	Jan. 14, 1945	T,E	I	Discharge 2,780 gallons a minute. See log.
3486	96.5	Oct. 14, 1946	None	N	Unused irrigation well.
3487	e/ 103	May 1946	T,E	I	Discharge 1,550 gallons a minute.
3488	e/ 74.6	Jan. 1946	T,E	I	Discharge 1,180 gallons a minute.
3686	203.6	Oct. 16, 1946	None	N	Irrigation test well. See log.

No.	Location: Township and Range	Location: Section	Owner	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
3956	T.3 N.,R. 2 W.	NW¼NE¼ sec. 4	M.C.M.W.C.D.	-	-	700	8
3957	do.	NE¼NW¼ sec. 14	do.	1938	1,266	547	20
d/ 4001	T.2 N.,R. 2 W.	NE¼NE¼ sec. 22	do.	1929	1,112	492	20
d/ 4051	T.1 N.,R. 2 W.	SW¼SW¼ sec. 16	Roosevelt Irr. Dist.	-	954.8	200	20
4351	T.1 S.,R. 3 W.	NE¼NE¼ sec. 2	-	-	-	117	4
d/ 4401	T.1 N.,R. 3 W.	NW¼NW¼ sec. 34	Roosevelt Irr. Dist.	-	916.7	200	20
d/ 4711	T.1 N.,R. 4 W.	SW¼SW¼ sec. 31	do.	-	-	-	20
d/ 4712	do.	SW¼SE¼ sec. 34	do.	1929	903.9	212	20
4761	T.1 S.,R. 4 W.	NW¼SW¼ sec. 17	Blake	-	-	90	4

a/ Measuring point was usually top of casing, top of pump base, or top of well curb.

b/ T, turbine; C, cylinder; E, electric motor; G, gasoline or natural gas; W, wind; H, hand; O, Diesel.

No.	Water level Depth below measuring point (feet) a/	Date of measurement	Pump and power b/	Use of water c/	Remarks
3956	262.7	Oct. 16, 1946	None	N	Irrigation test well.
3957	e/ 216	Dec. 29, 1946	T,E	I	Discharge 1,820 gallons a minute.
4001	e/ 155	Mar. 15, 1944	T,E	I	Discharge 2,680 gallons a minute.
4051	81.7	June 10, 1946	T,E	I	Discharge 2,780 gallons a minute.
4351	3.4	Oct. 25, 1946	None	N	Unused domestic well.
4401	56.7	do.	T,E	I	-
4711	e/ 65	Jan. 14, 1945	T,E	I	-
4712	48.5	Oct. 25, 1946	T,E	I	-
4761	6.1	do.	None	N	Unused domestic well.

c/ I, irrigation; S, stock; D, domestic; P, public supply; N, none.
d/ See table 6 for analysis of water from this well.
e/ Water level reported.

Table 6. Analyses of water samples from typical wells in the Salt River Valley, Pinal and Maricopa Counties, Arizona
Numbers correspond to numbers in table 5.
(Parts per million except specific conductance and percent sodium)

Well No.	Date of collection	Depth (ft.)	Specific conductance ($K \times 10^5$ at 25°C.)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium
851 a/	Mar.19,1946	350	160	89	16	214	136	78	392	1.8	5.0	863	288	62
1457 a/	Mar.20,1946	100	406	113	66	710	476	461	860	.0	19	c/2460	554	74
1601 b/	July 2,1946	-	187	25	19	352	342	202	269	-	30	1068	140	84
1602 b/	Oct.18,1945	161	141	49	23	217	307	82	236	-	12	773	217	69
2156 a/	Mar.20,1946	-	374	248	67	460	244	344	940	1.3	7.8	2190	894	53
2256 a/	do.	-	252	138	47	302	151	112	675	.2	4.0	1350	538	55
2855 a/	Apr. 2,1946	-	61.8	54	22	40	204	38	56	.4	33	344	225	28
2951 b/	July21,1942	-	146	137	45	81	210	93	266	-	71	798	527	25
3051 b/	Oct.16,1945	182	302	94	53	478	439	208	599	-	84	1736	452	70
3052 b/	Oct. 2,1945	-	394	120	52	666	568	354	776	-	25	2277	514	74
3386 b/	May 15,1946	218	388	316	120	370	324	692	738	-	68	2466	1280	39
3387 a/	Jan.16,1946	210	181	194	53	111	288	188	335	.3	48	1070	702	26
3486 a/	Jan.17,1946	330	89.8	86	30	53	176	88	145	.8	13	502	338	25
3487 b/	June12,1946	280	95.2	79	33	60	196	100	130	-	16	516	332	28
3488 a/	Jan.17,1946	207	53.2	53	21	27	202	36	43	.4	16	296	218	21
4001 a/	Feb. 7,1946	492	36.5	20	9.6	45	144	23	22	1.6	13	205	90	52
4051 b/	May 14,1946	200	208	137	55	204	159	324	358	-	50	1208	568	44
4401 b/	May 19,1946	200	628	268	140	926	157	927	1450	-	136	3926	1240	62
4711 a/	Feb. 7,1946	-	496	348	128	523	145	521	1240	1.0	149	2980	1400	45
4712 b/	Apr.29,1946	212	582	234	135	870	168	990	1220	-	161	3694	1140	62

a/ Analyzed by Geological Survey.
b/ Analyzed by Salt River Valley Water Users' Association.
c/ Contains 40 parts per million of borate (BO_3).

Table 7. Analyses of water samples from surface sources in the Salt River Valley, Maricopa County, Arizona

Analyses by Salt River Valley Water Users' Association.
(Parts per million except specific conductance and percent sodium).

	1	2	3
Date of collection	Dec. 4, 11, 18, 25, 1944	May 7, 14, 21, 28, 1945	Mar. 14, 1945
Calcium (Ca)	46	44	268
Magnesium (Mg)	21	13	118
Sodium (Na) / Potassium (K)	105	141	1040
Bicarbonate (HCO_3)	202	163	371
Sulfate (SO_4)	51	40	783
Chloride (Cl)	150	209	1610
Nitrate (NO_3)	1	1	17
Dissolved solids:			
Sum - ppm	475	529	4021
- tons/acre-foot	.65	.72	5.47
Total hardness as $CaCO_3$	202	164	1150
Specific conductance ($K \times 10^5$ at 25°C.)	90.6	103	661
Percent sodium	53	65	66

1. Arizona Canal at Granite Reef Dam.
2. South Canal at Granite Reef Dam.
3. Gila River at Gillespie Dam (average composition).

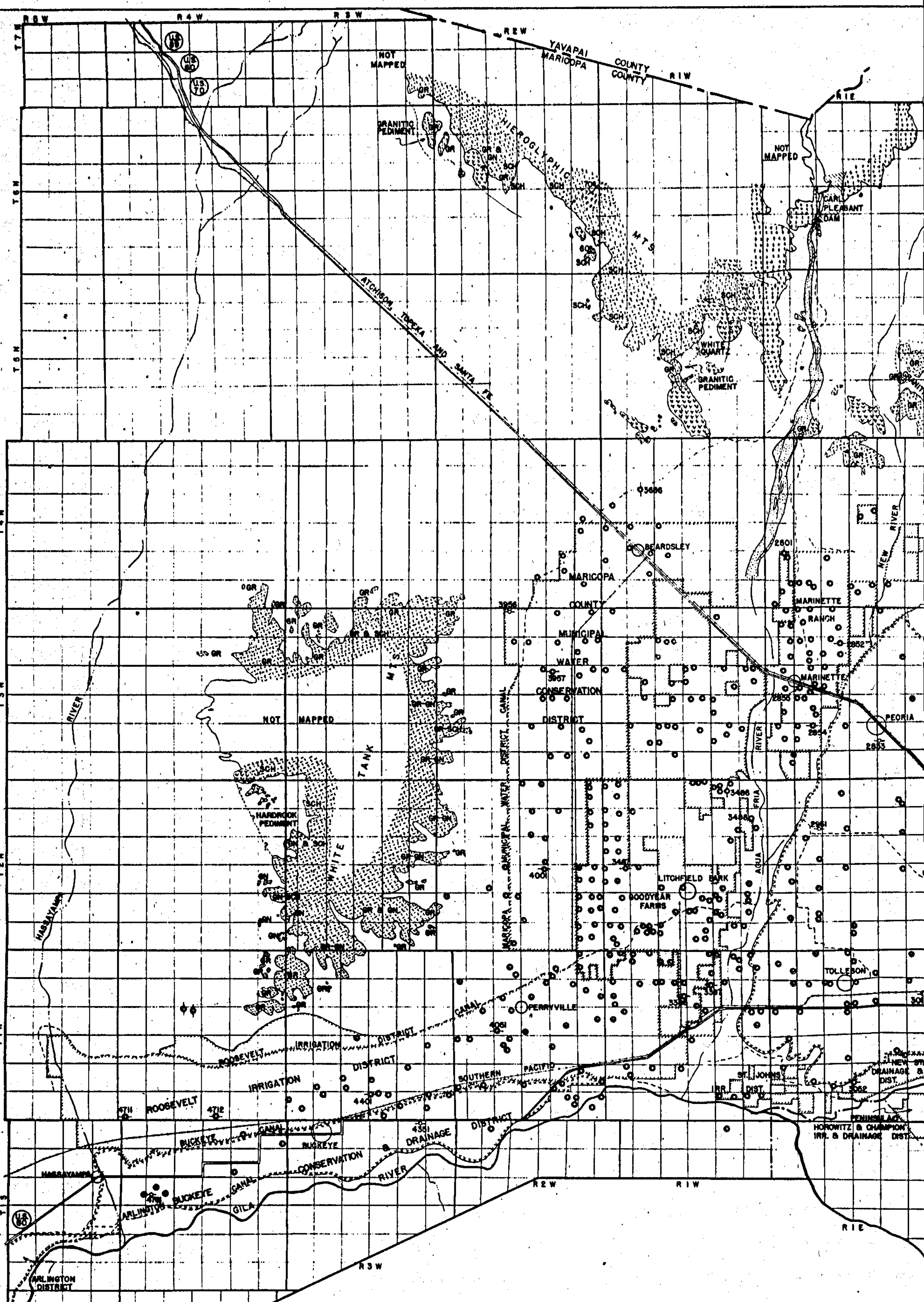

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PLATE I. MAP OF SALT RIVER VALLEY AREA, ARIZONA

SHOWING GEOLOGY, LOCATIONS OF WELLS USED FOR IRRIGATION AND WATER LEVEL OBSERVATION, AND IRRIGATED AREAS.

SCALE

1 0 1 2 3 4 5 6 7 8 9 MILES

EXPLANATION

MATERIAL	WATER-BEARING PROPERTIES
RECENT ALLUVIUM	YIELDS LARGE VOLUMES OF WATER FROM SHALLOW SAND AND GRAVEL LAYERS UNDERLYING STREAM CHANNELS.
PLEISTOCENE ALLUVIUM	PRINCIPAL AQUIFER OF AREA. YIELDS WATER FROM SAND AND GRAVEL LAYERS.
OLDER SEDIMENTARY ROCKS	YIELDS WARM WATER TO WELLS.
QUATERNARY VOLCANIC ROCKS	YIELDS LIMITED SUPPLIES FROM FRACTURES AND WEATHERED ZONES.
TERTIARY-CRETACEOUS VOLCANIC ROCKS	YIELDS LIMITED SUPPLIES FROM FRACTURES AND WEATHERED ZONES.
QUARTZITE	ESSENTIALLY NON-WATER-BEARING IN AREA.
GR / GN / SCH — GRANITE, GNEISS, OR SCHIST	YIELDS VERY LIMITED SUPPLIES FROM FRACTURES AND WEATHERED ZONES.

CONTACT NOT ACCURATELY LOCATED

30 STRIKE AND DIP

MINE

IRRIGATION WELL

IRRIGATION WELL USED FOR WATER LEVEL OBSERVATION

UNUSED IRRIGATION WELL

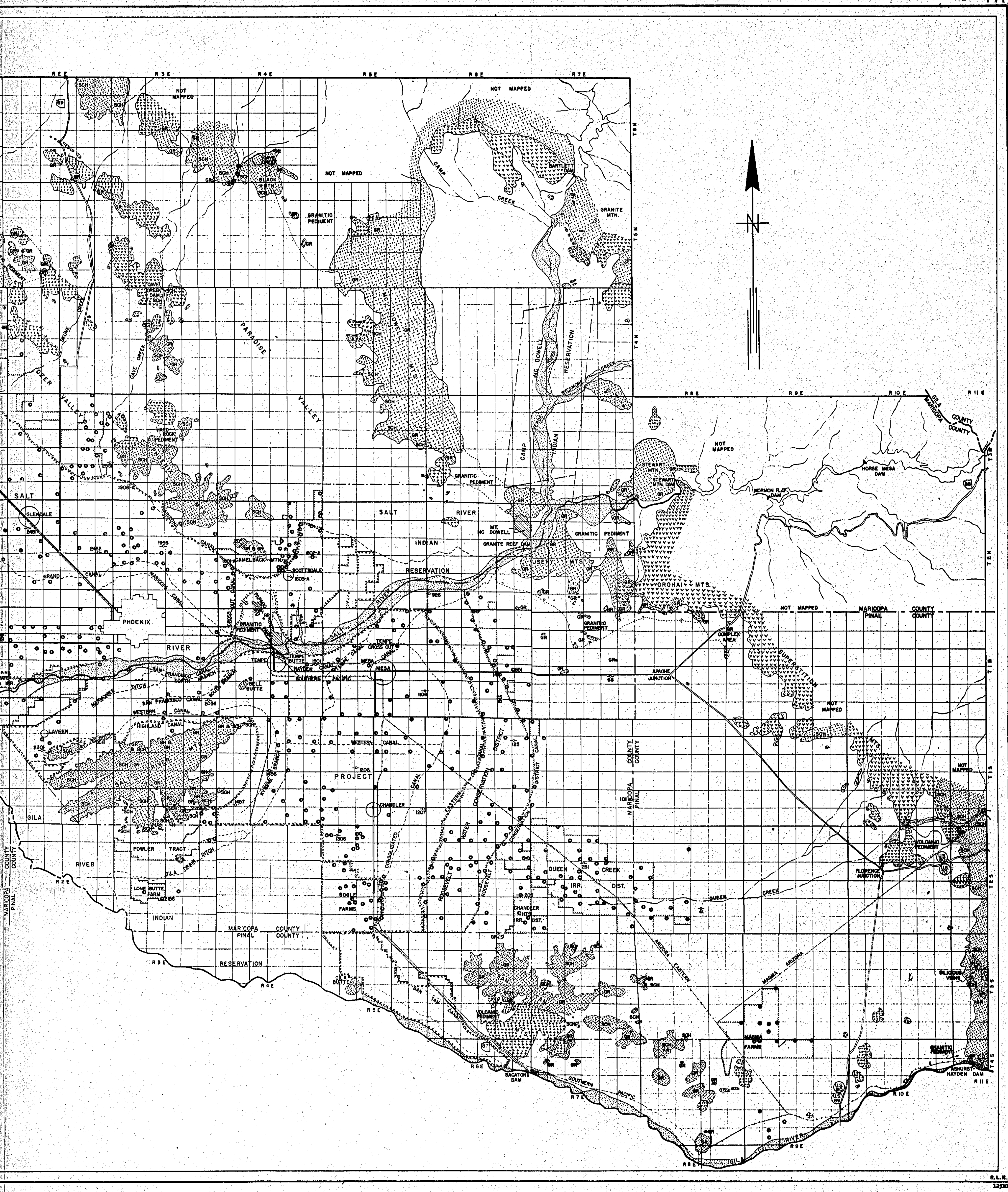
DOMESTIC WELL USED FOR WATER LEVEL OBSERVATION

LAND IRRIGATED PRIMARILY WITH SURFACE WATER

LAND IRRIGATED PRIMARILY WITH GROUND WATER

GEOLOGY BY H.N. WALCOTT; WELL LOCATIONS BY F.I. BLUHM AND J.R MOOSEAU, JR.

Plate


R2E
R3E
R4E
R5E
R6E
R7E
R8E
R9E
R10E
R11E
T6N
T5N
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
NOT MAPPED
GRANITIC PEDIMENT
BARTLETT DAM
GRANITE MTN.
CAMP CREEK
CAVE CREEK
BLACK MTN.
PARADISE VALLEY
DEER VALLEY
HARD ROCK PEDIMENT
MC DOWELL MTS.
MC DOWELL RIVER
INDIAN RESERVATION
CAMP VERDE
SYCAMORE CREEK
STEWART MTN.
STEWART MTN. DAM
MORMON FLAT DAM
HORSE MESA DAM
GILA COUNTY
MARICOPA COUNTY
PINAL COUNTY
SALT RIVER
INDIAN RESERVATION
MT. MC DOWELL
GRANITE REEF DAM
USERY MTS.
GRANITIC PEDIMENT
GLENDALE
GRAND CANAL
ARIZONA CANAL
CAMELBACK MTN.
SCOTTSDALE
PHOENIX
CROSS CUT CANAL
PAPAGO
TEMPE
TEMPE BUTTE
TEMPE CROSS CUT
MESA
MESA CANAL
CONSOLIDATED CANAL
SOUTHERN PACIFIC
SAN FRANCISCO CANAL
NORTH BRANCH
SOUTH BRANCH
BELL BUTTE
WESTERN CANAL
HIGHLAND CANAL
LAVEEN
SALT RIVER MTS.
KYRENE BRANCH
WESTERN CANAL
PROJECT
CHANDLER
EASTERN CANAL
WATER CONSERVATION DISTRICT
ROOSEVELT
ROOSEVELT CANAL
QUEEN CREEK IRR. DIST.
CHANDLER HTS. IRR. DIST.
BOGLE FARMS
GILA RIVER
FOWLER TRACT
GILA DRAIN DITCH
LONE BUTTE FARM
INDIAN RESERVATION
GILA BUTTE
SAN TAN CANAL
SAN TAN MTS.
VOLCANIC PEDIMENT
SACATON DAM
SOUTHERN PACIFIC
ARIZONA EASTERN
MAGMA ARIZONA
MAGMA FARMS
APACHE JUNCTION
COMPLEX AREA
SUPERSTITION MTS.
OROHAI MTS.
FLORENCE JUNCTION
QUEEN CREEK
SILICIOUS VEINS
ASHURST-HAYDEN DAM
R.L.H.
12530

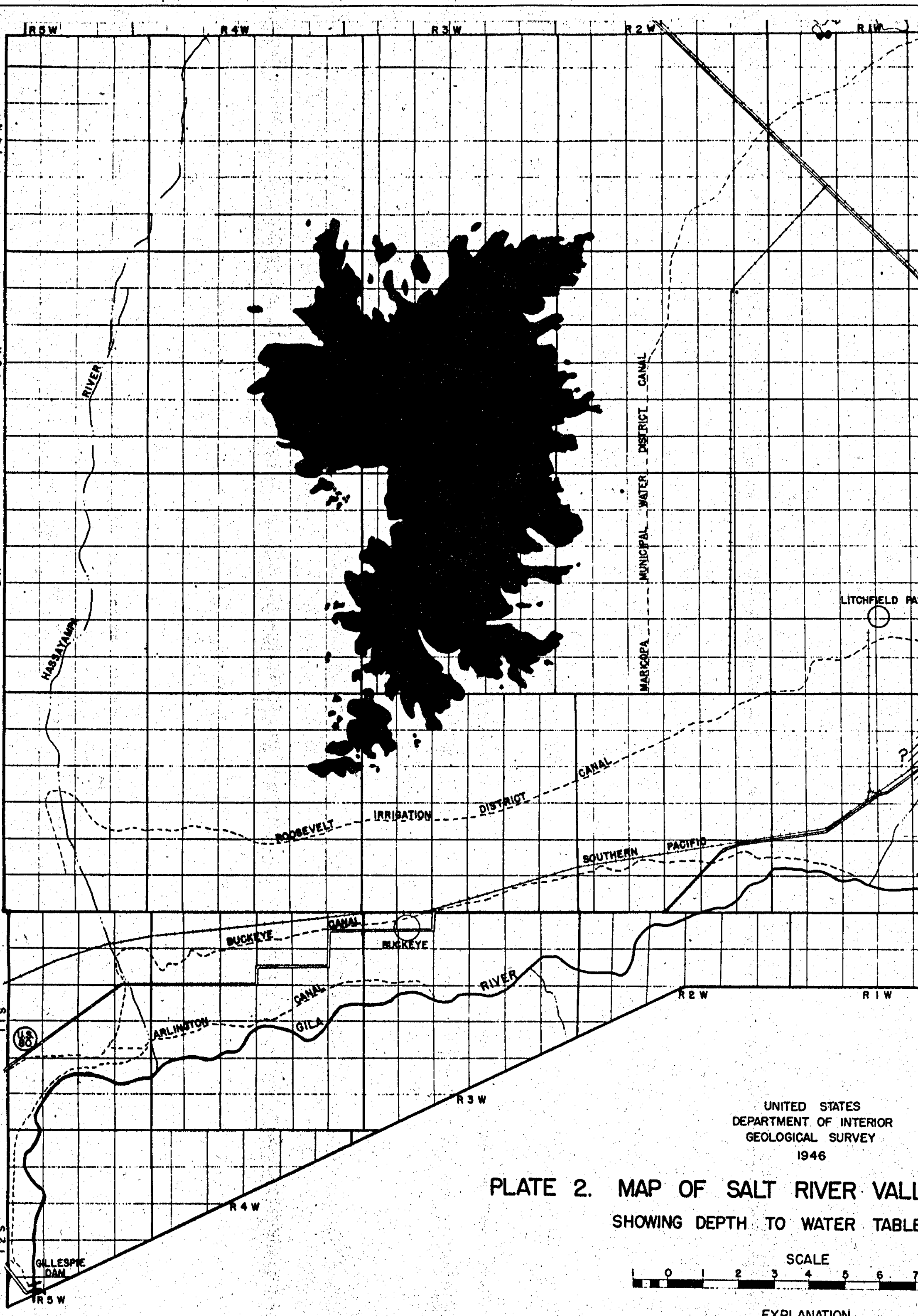


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PLATE 2. MAP OF SALT RIVER VALL

SHOWING DEPTH TO WATER TABLE

SCALE

1 0 1 2 3 4 5 6 7

EXPLANATION

WATER LEVEL, IN FEET BELOW LAND S

0 – 10

10 – 50

50 – 150

OVER 150

MOUNTAIN AREAS OF HARDROCK

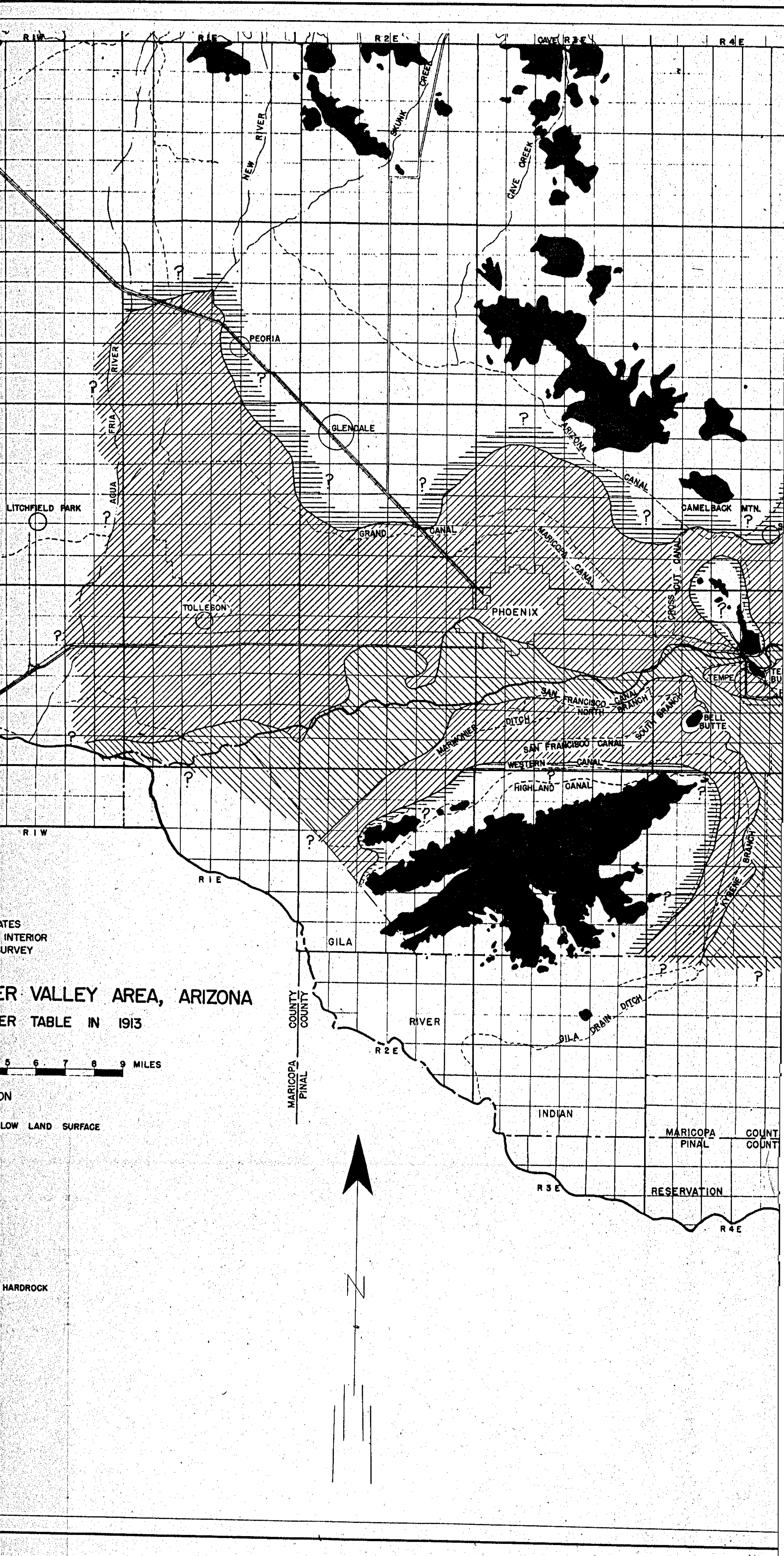
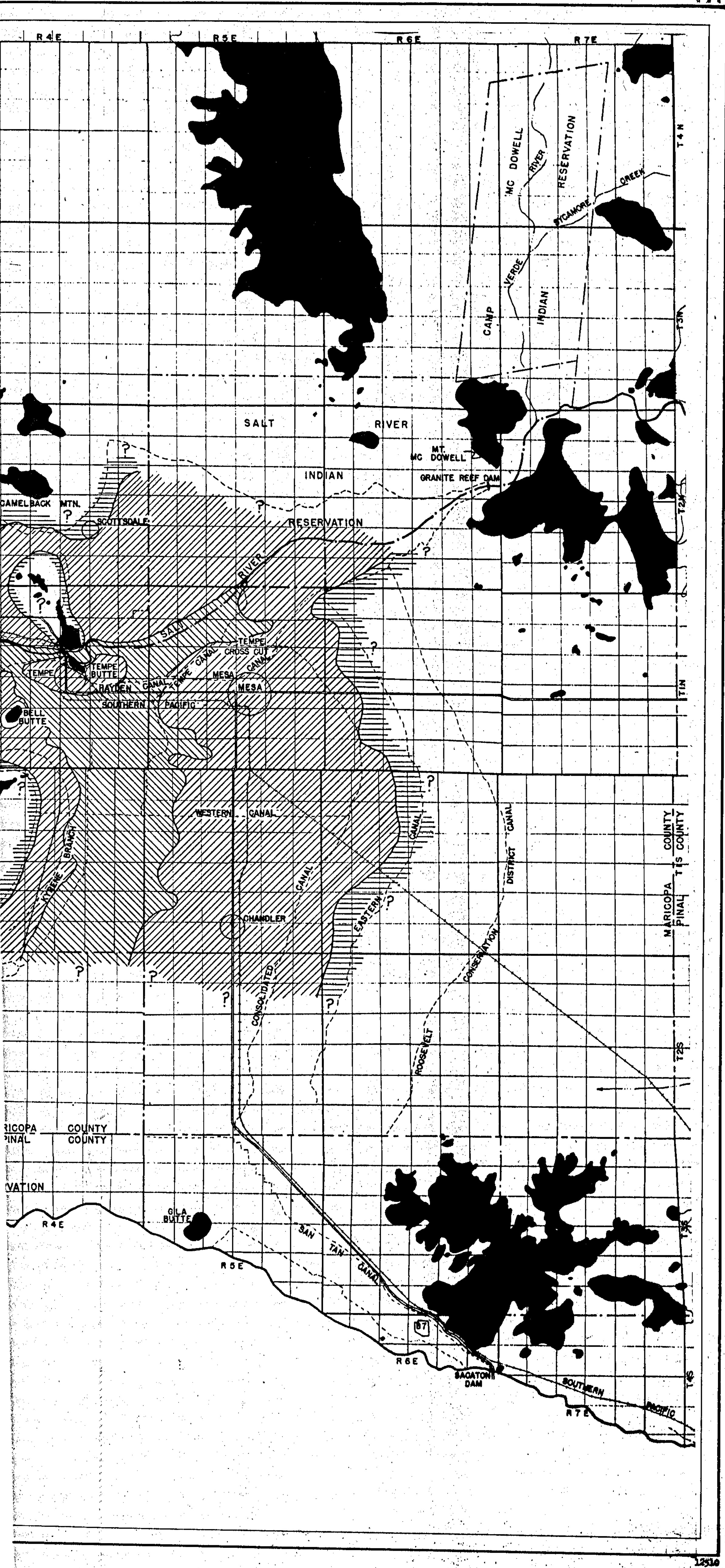

ATES
INTERIOR
URVEY
ER VALLEY AREA, ARIZONA
ER TABLE IN 1913
5 6 7 8 9 MILES
ON
LOW LAND SURFACE
HARDROCK
R 1 W
R 1 E
R 2 E
R 3 E
R 4 E
CAVE
NEW RIVER
SKUNK CREEK
CAVE CREEK
PEORIA
GLENDALE
AGUA FRIA RIVER
LITCHFIELD PARK
ARIZONA CANAL
GRAND CANAL
MARICOPA CANAL
CAMELBACK MTN.
CROSS CUT CANAL
PHOENIX
TOLLESON
TEMPE
SAN FRANCISCO CANAL NORTH BRANCH
SOUTH BRANCH
BELL BUTTE
MARMONIER DITCH
SAN FRANCISCO CANAL
WESTERN CANAL
HIGHLAND CANAL
KYRENE BRANCH
GILA RIVER
GILA DRAIN DITCH
MARICOPA COUNTY
PINAL COUNTY
INDIAN RESERVATION
N

Plate 2



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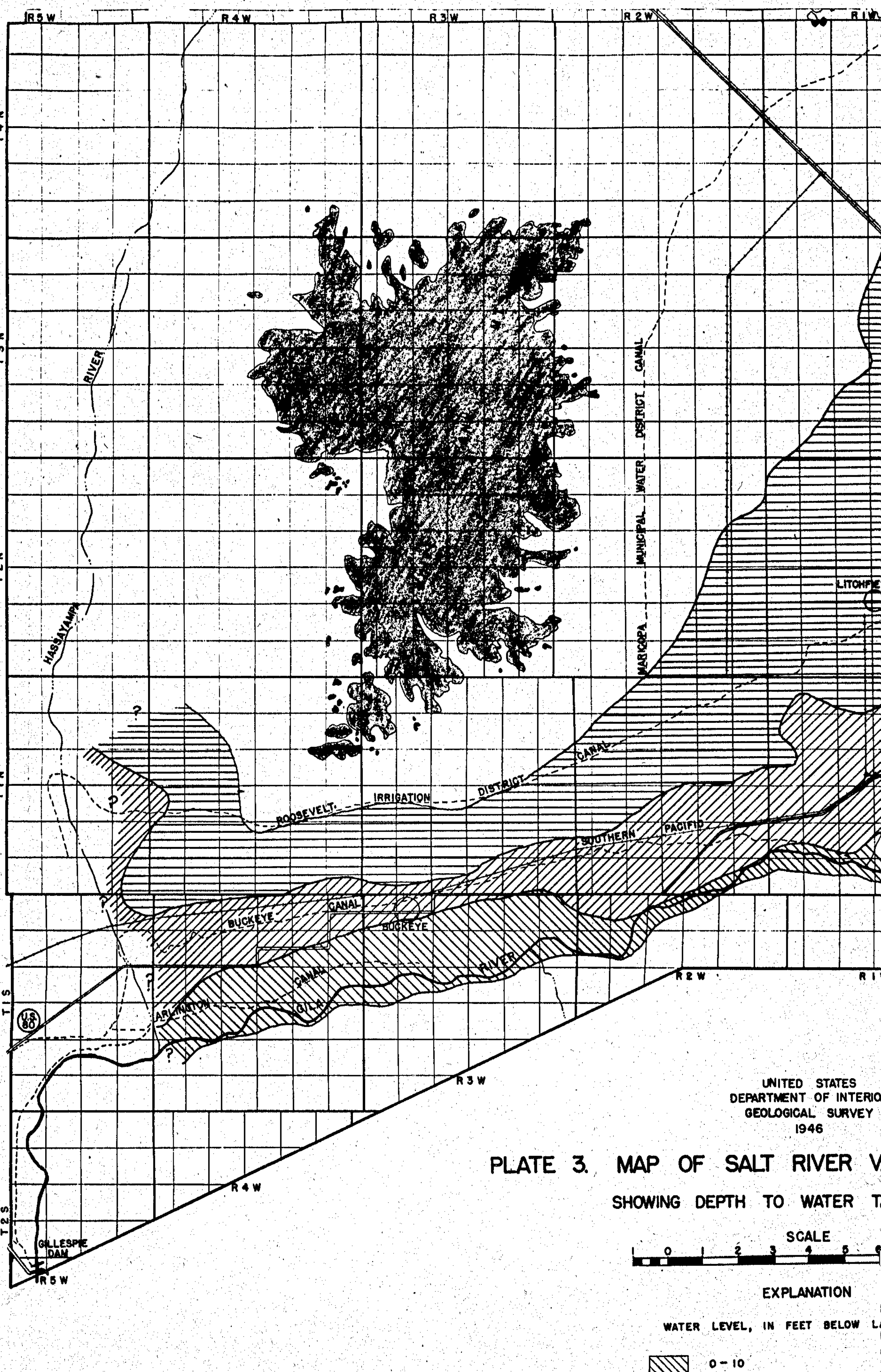

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PLATE 3. MAP OF SALT RIVER V

SHOWING DEPTH TO WATER T

SCALE

0 1 2 3 4 5 6

EXPLANATION

WATER LEVEL, IN FEET BELOW L

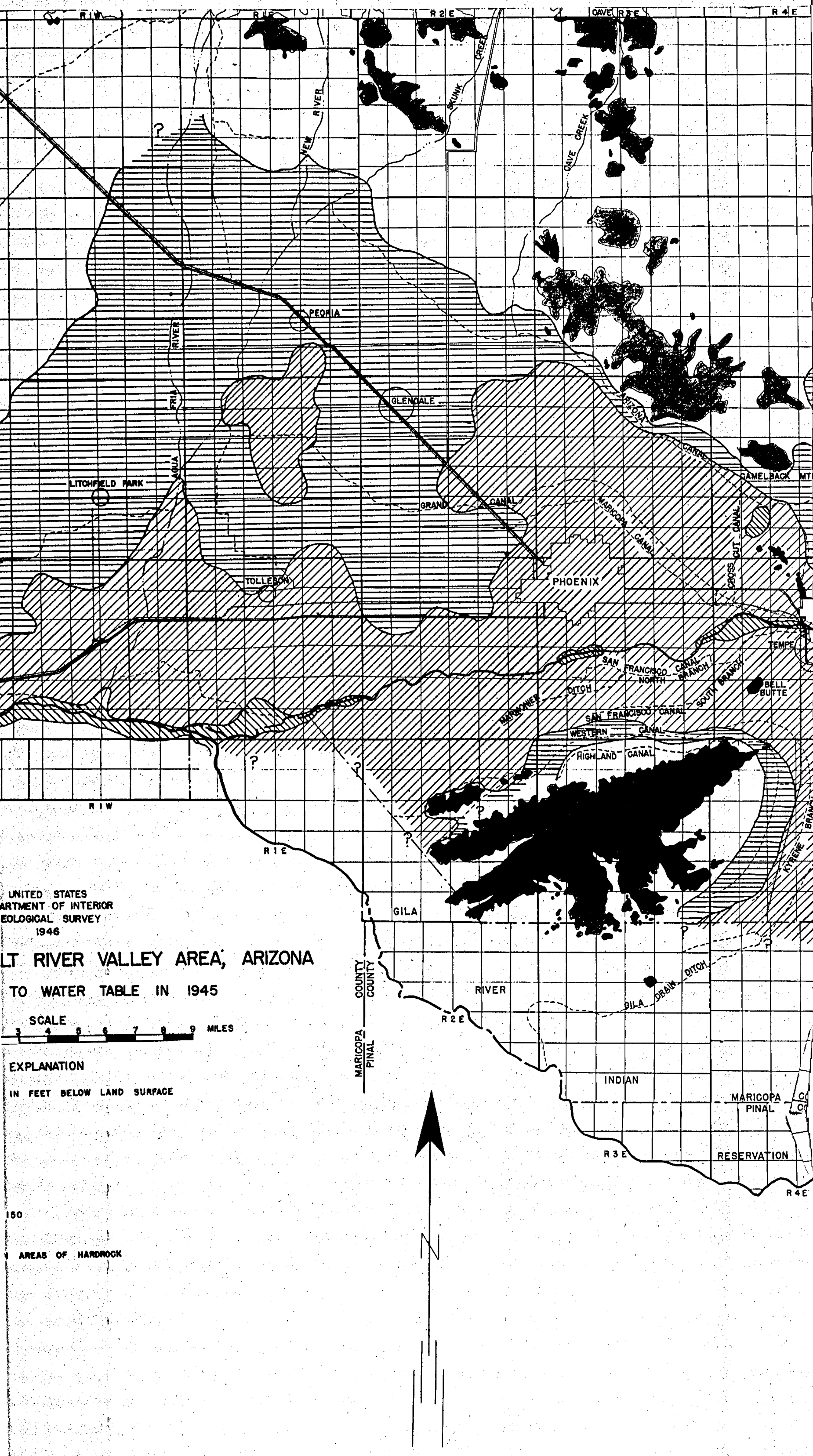
0 – 10

10 – 50

50 – 150

OVER 150

MOUNTAIN AREAS OF HARDRO



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LT RIVER VALLEY AREA, ARIZONA

TO WATER TABLE IN 1945

SCALE

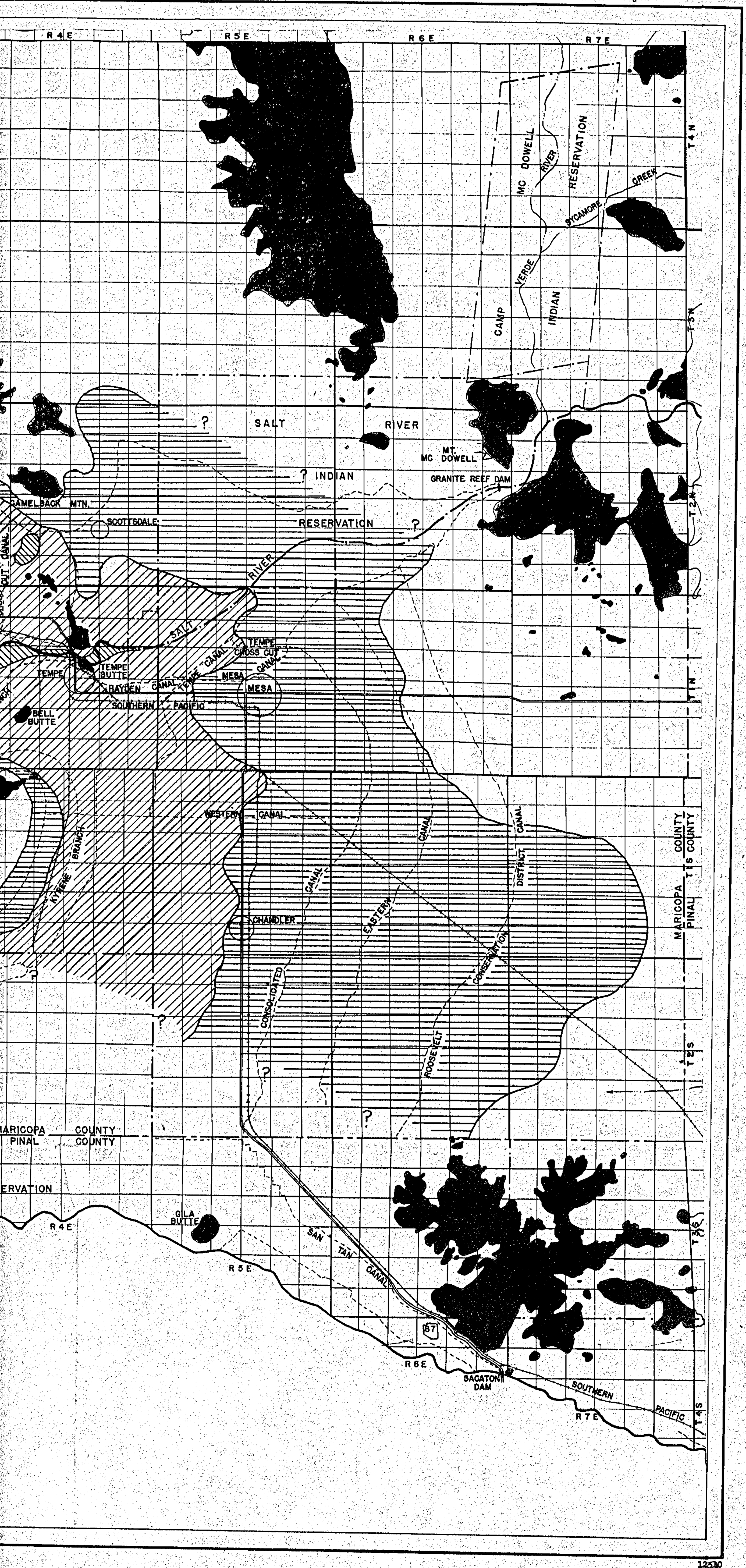
3 4 5 6 7 8 9 MILES

EXPLANATION

IN FEET BELOW LAND SURFACE

150

AREAS OF HARDROCK


R4E
R5E
R6E
R7E
T4N
T3N
T2N
T1N
T1S
T2S
T3S
T4S
MC DOWELL
RIVER
RESERVATION
CAMP
VERDE
INDIAN
SYCAMORE
CREEK
SALT
RIVER
INDIAN
RESERVATION
MT. MC DOWELL
GRANITE REEF DAM
CAMELBACK MTN.
SCOTTSDALE
TEMPE
TEMPE BUTTE
HAYDEN
CANAL
TEMPE CANAL
SOUTHERN
PACIFIC
MESA
TEMPE CROSS CUT CANAL
BELL BUTTE
WESTERN CANAL
KYRENE BRANCH
CHANDLER
CONSOLIDATED CANAL
EASTERN CANAL
ROOSEVELT
CONSERVATION DISTRICT CANAL
MARICOPA COUNTY
PINAL COUNTY
GILA BUTTE
SAN TAN CANAL
87
SACATON DAM
SOUTHERN PACIFIC

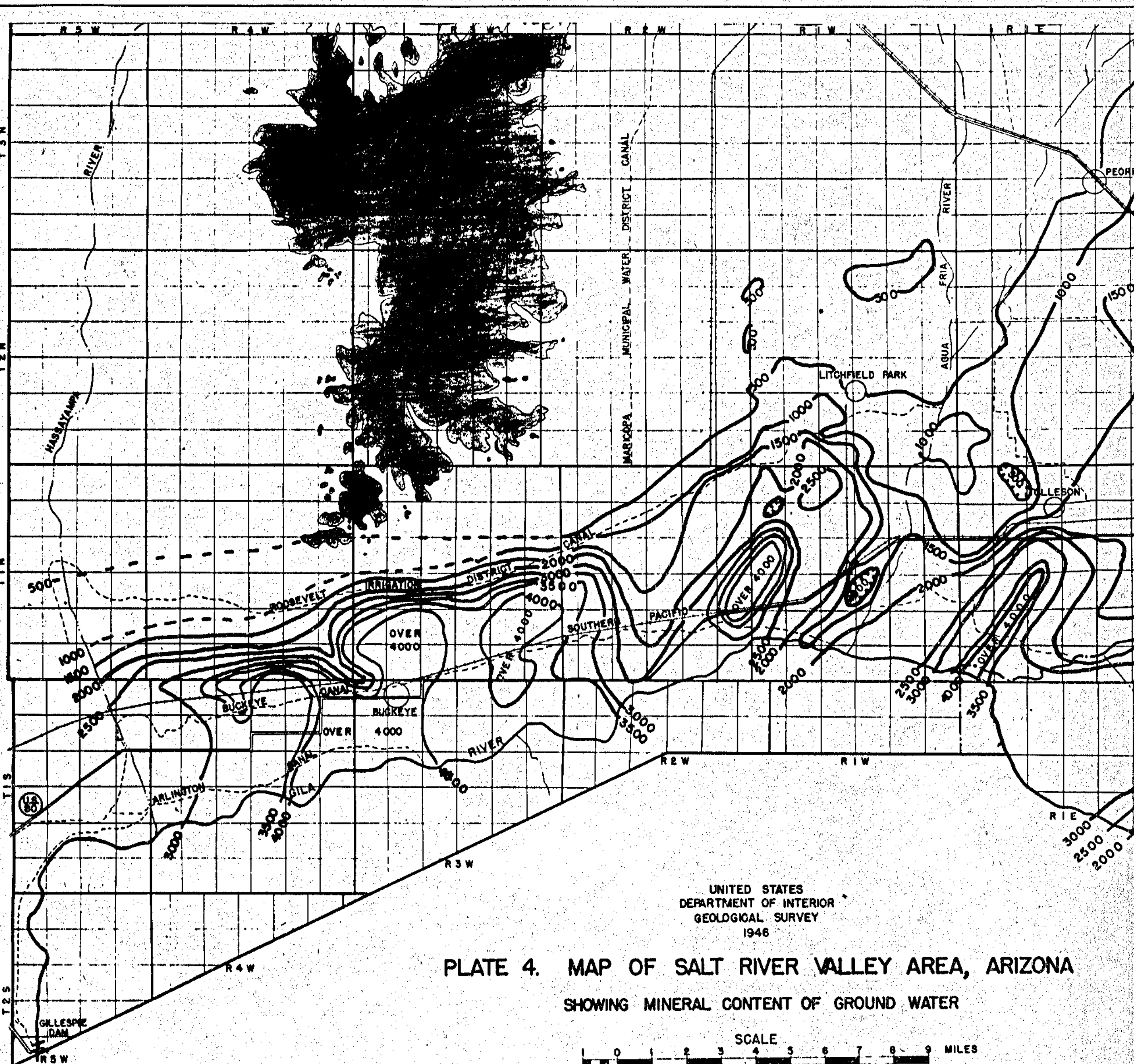


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PLATE 4. MAP OF SALT RIVER VALLEY AREA, ARIZONA

SHOWING MINERAL CONTENT OF GROUND WATER

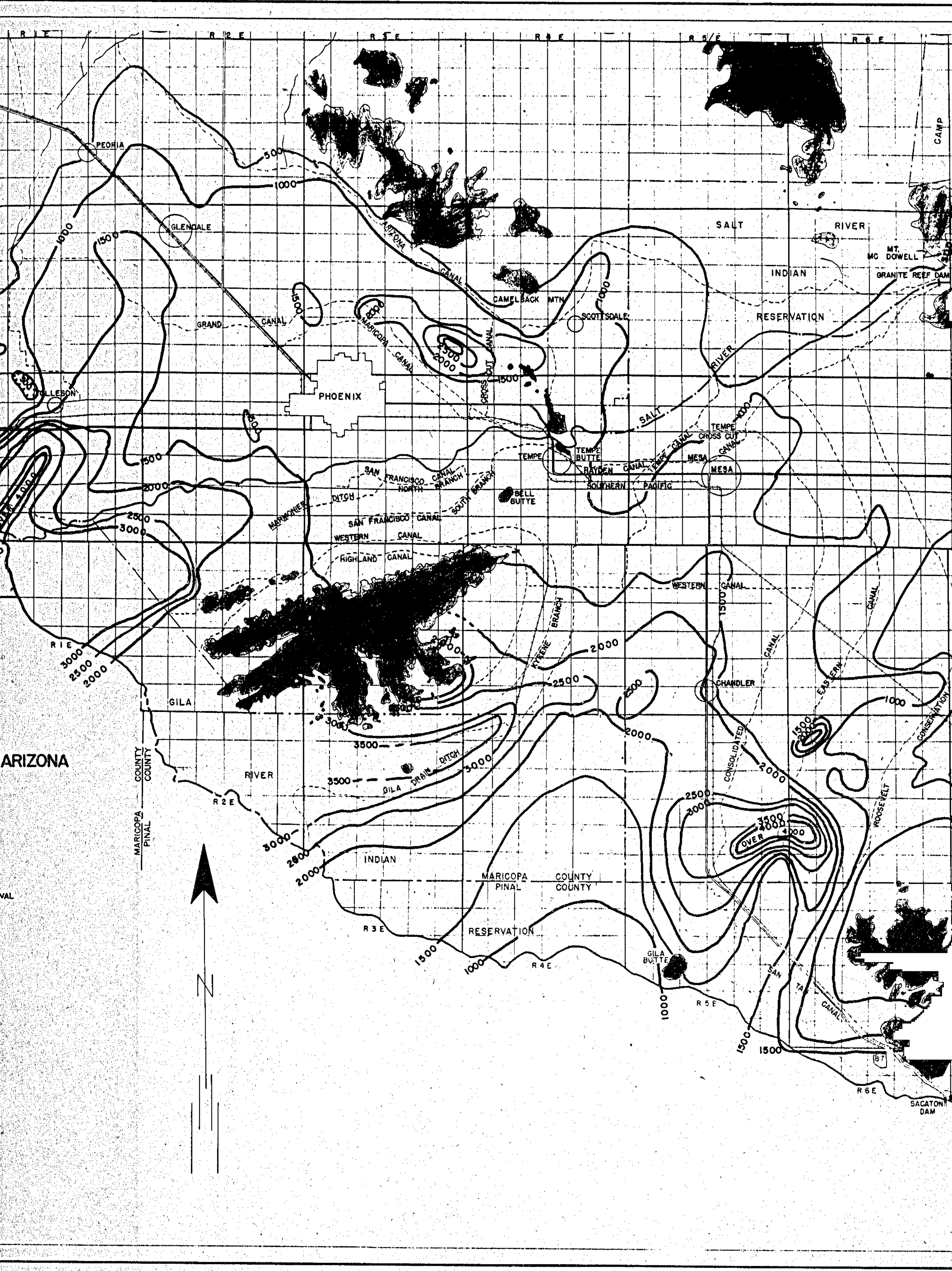
SCALE

1 0 1 2 3 4 5 6 7 8 9 MILES

EXPLANATION

500 — LINES SHOWING TOTAL MINERAL CONTENT OF GROUND WATER. INTERVAL IS 500 PARTS PER MILLION.

MOUNTAIN AREAS OF HARDROCK



ARIZONA
R 1 E
R 2 E
R 3 E
R 4 E
R 5 E
R 6 E
PEORIA
GLENDALE
TOLLESON
PHOENIX
SCOTTSDALE
TEMPE
TEMPE BUTTE
MESA
CHANDLER
CAMELBACK MTN
BELL BUTTE
GILA BUTTE
MT. MC DOWELL
GRANITE REEF DAM
SACATON DAM
CAMP
SALT RIVER INDIAN RESERVATION
SALT RIVER
GILA RIVER
GILA RIVER INDIAN RESERVATION
ARIZONA CANAL
GRAND CANAL
MARICOPA CANAL
CROSS CUT CANAL
TEMPE CROSS CUT CANAL
TEMPE CANAL
HAYDEN CANAL
SOUTHERN PACIFIC
SAN FRANCISCO CANAL NORTH BRANCH
SAN FRANCISCO CANAL SOUTH BRANCH
SAN FRANCISCO CANAL
MARMONIER DITCH
WESTERN CANAL
HIGHLAND CANAL
KYRENE BRANCH
GILA DRAIN DITCH
CONSOLIDATED CANAL
EASTERN CANAL
ROOSEVELT CANAL
CONSERVATION
SAN TAN CANAL
MARICOPA COUNTY
PINAL COUNTY
87
N
500
1000
1500
2000
2500
3000
3500
OVER 4000

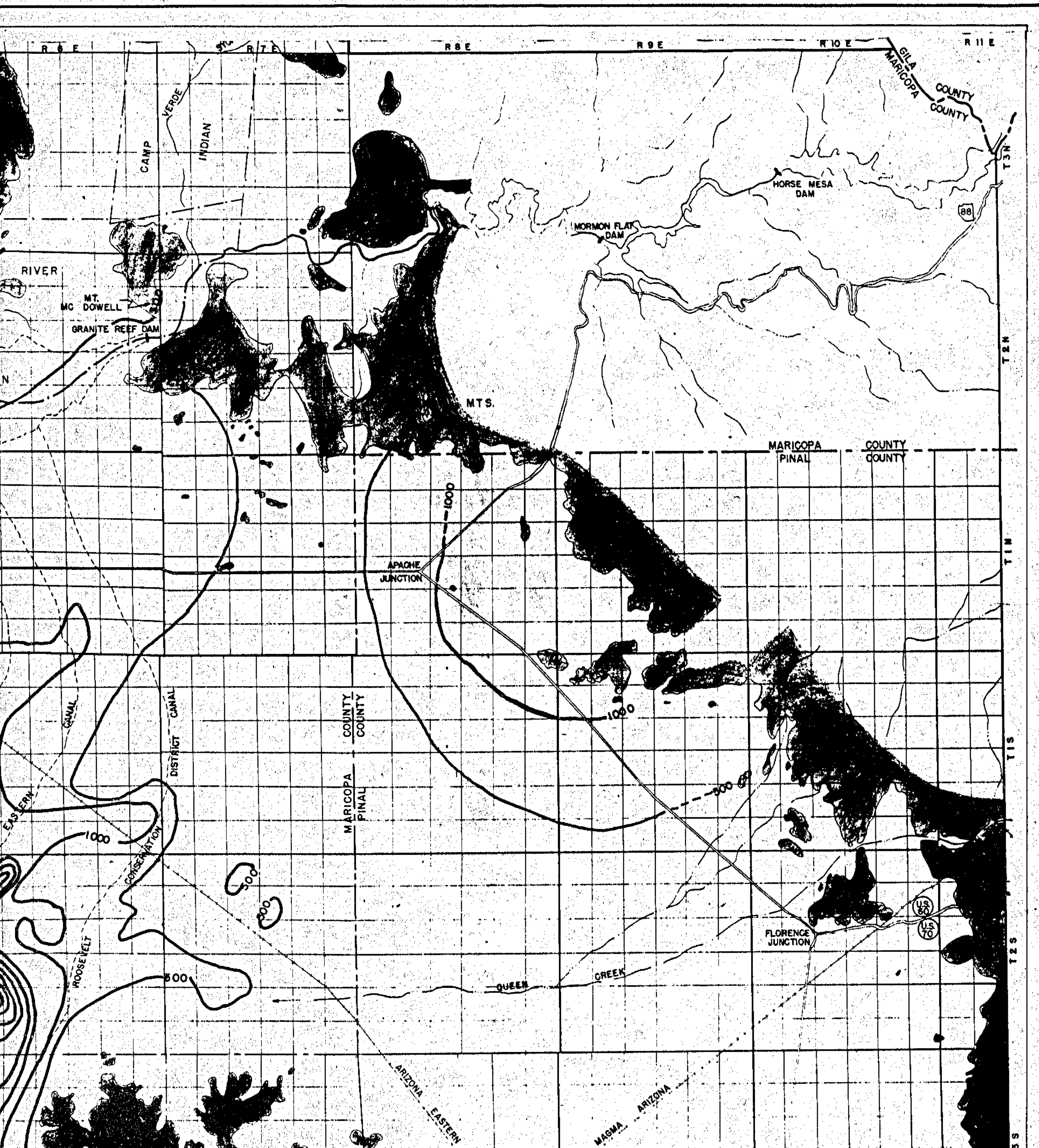

R 6 E
R 7 E
R 8 E
R 9 E
R 10 E
R 11 E
GILA COUNTY
MARICOPA COUNTY
T3N
T2N
T1N
T1S
T2S
T3S
T4S
CAMP VERDE INDIAN
RIVER
MT. MC DOWELL
GRANITE REEF DAM
HORSE MESA DAM
MORMON FLAT DAM
MTS.
MARICOPA COUNTY
PINAL COUNTY
1000
APACHE JUNCTION
500
EASTERN CANAL
CONSERVATION DISTRICT CANAL
ROOSEVELT
MARICOPA COUNTY
PINAL COUNTY
FLORENCE JUNCTION
U.S. 60
U.S. 70
88
QUEEN CREEK
ARIZONA EASTERN
MAGMA ARIZONA
CANAL
87
SACATON DAM
SOUTHERN PACIFIC
U.S. 80
U.S. 89
ASHURST-HAYDEN DAM
GILA RIVER
R 6 E
R 7 E
R 8 E
R 9 E
R 10 E
R 11 E
12510

Figure 1.--Graphs showing fluctuations of water level in observation wells in the Salt River Valley, Maricopa County, Arizona

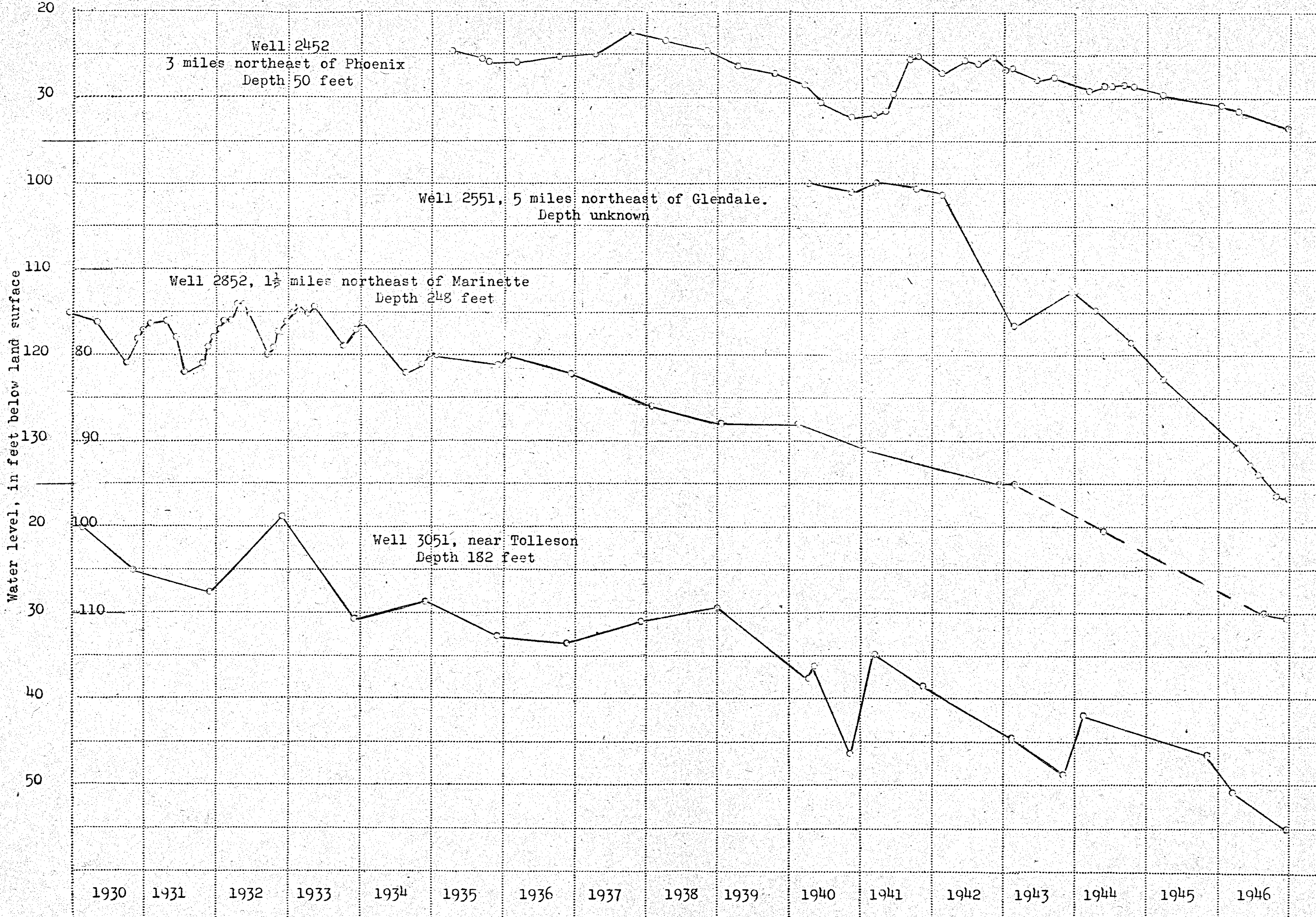


Figure 2.—Graphs showing fluctuations of water level in observation wells in the Salt River Valley, Maricopa County, Arizona

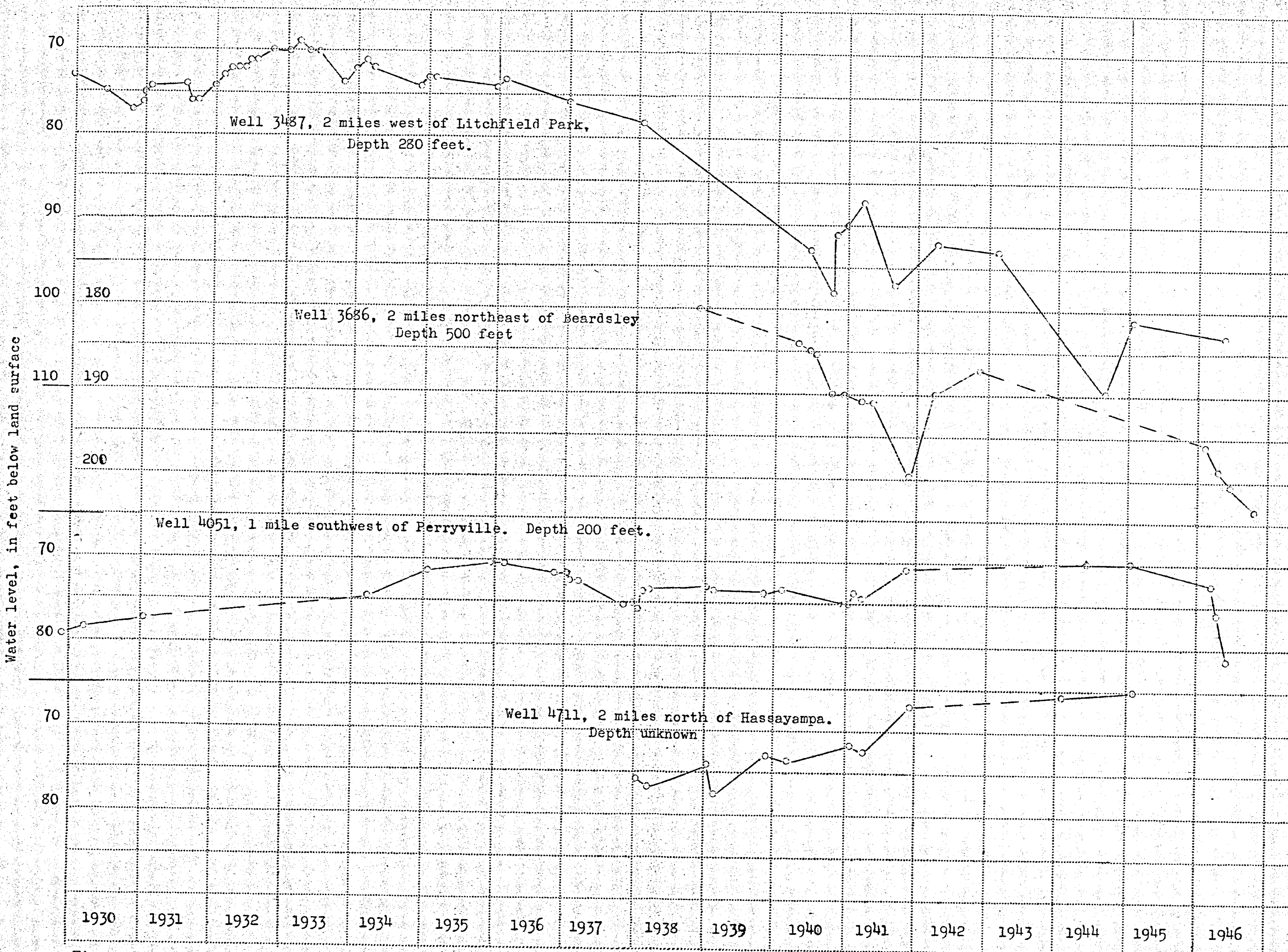


Figure 3.--Graphs showing fluctuations of water level in observation wells in the Salt River Valley, Maricopa County, Arizona