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Ground-water resources of the Holbrook area, Navajo County, Arizona

By

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With a section on quality of water

By

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

Tucson, Arizona

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INTRODUCTION

Purpose and cooperation

The need for state regulation of ground-water resources in Arizona has become increasingly apparent. Inasmuch as such regulation must be based upon adequate information as to the quantity, quality, and use of the ground water, as well as its source and movement, the Arizona State Legislature in 1945 appropriated funds for the investigation of the important ground-water basins in the state. The investigations are 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.

Most of the field work in the Holbrook area was done during the summer of 1946, by H. M. Babcock, engineer, and C. T. Snyder, geologist, under the direct supervision of S. F. Turner, District Engineer (Ground Water), of the Federal Geological Survey. Periodic water-level measurements have been made in selected wells in the area since 1944.

Analyses of water samples were made by J. D. Hem and R. T. Kiser, chemists of the Quality of Water Division of the Geological Survey.

Location

The area described in this report is a part of the Colorado Plateau. The area covers about 3,200 square miles and consists of the portion of Navajo County between the Mogollon Rim on the south and the Navajo Indian Reservation on the north (see pl. 2). A detailed investigation was made of the artesian area along the Little Colorado River between Holbrook and Joseph City. The section on ground-water resources deals primarily with this artesian area (see pl. 3).

Climatological data

The climate of the Holbrook area ranges from humid in the forested areas near the Mogollon Rim to arid in the desert north of the Little Colorado River. The mean annual temperature ranges from about 47° F. at Heber to about 55° F. at Holbrook, according to the records of the U. S. Weather Bureau. The mean annual rainfall at Heber is 18.9 inches (elev. 6,484 feet), and 9.2 inches at Holbrook (elev. 5,069 feet).

Agricultural development

The Holbrook area is primarily a grazing country, and one of the principal problems of the area is to find sufficient water for cattle and sheep.

Several small tracts of land along the major drainage channels of the area are farmed. In most of the farmed areas, a large part of the irrigation water is obtained from surface flow of the streams. The Joseph City Irrigation Company, with about 1,600 acres under cultivation, obtains part of its irrigation water from flowing wells and the remainder from flow of the Little Colorado River. About 500 acres of land, south of the Little Colorado River between Holbrook and Joseph City, is supplied with irrigation water from wells. About 1,100 acres of pasture land in this vicinity is naturally sub-irrigated. This is the only part of the entire area where there has been any extensive use of ground water for irrigation purposes, although during the past few years some irrigation wells have been drilled near Snowflake.

Acknowledgments

The writers are much indebted to Professor E. D. McKee, of the Geology Department of the University of Arizona, for his helpful criticism of this report.

Previous investigations

The principal reports of earlier investigations that were used as references in the preparation of this report are listed below:

1. Gregory, H. E., The Navajo country - a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah: U. S. Geol. Survey Water-Supply Paper 380, 1916.
2. Gregory, H. E., Geology of the Navajo country - a reconnaissance of parts of Arizona, New Mexico, and Utah: U. S. Geol. Survey Prof. Paper 93, 1917.
3. McKee, E. D., the Coconino sandstone - its history and origin: Carnegie Inst. Washington Pub. 440, pt. 7, pp. 77-115, 1934.
4. Stoyanow, A. A., Correlation of Arizona formations: Geol. Soc. America Bull., vol. 47, no. 4, pp. 459-540, Apr. 30, 1936.
5. McKee, E. D., The environment and history of the Toroweap and Kaibab formations of Arizona and Utah: Carnegie Inst. Washington Pub. 492, 1938.
6. Harrell, M. A., and Eckel, E. B., Ground-water resources of the Holbrook region, Ariz.: U. S. Geol. Survey Water-Supply Paper 836-B, 1939.
7. McKee, E. D., Some stratigraphic principles illustrated by Paleozoic deposits in Northeastern Ariz.: Am. Jour. Sci., vol. 241, pp. 101-108, 1943.
8. Stoyanow, A. A., Paleozoic paleogeography of Arizona: Geol. Soc. America Bull., vol. 53, no. 9, pp. 1255-1282, Sept. 1, 1942.

A more complete list of earlier reports upon the geology and ground-water resources of the area is contained in the paper by Harrell and Eckel.

Maps and field work

A limited amount of geologic field work was done in this investigation. The geologic map, plate 2, was adapted from that of Harrell and Eckel[1/]. The discussion of geology contained herein was principally adapted from the reports listed in the section of "Previous investigations."

The map of the artesian area, plate 3, was based upon topographic maps of the Little Colorado River Valley made by the Federal Geological Survey. Well locations and irrigated lands were plotted from aerial photographs and field observation. Well records and discharge measurements were obtained between June and August 1946.

LAND FORMS

The Holbrook area occupies a portion of the Colorado Plateau province, a region of gently folded and faulted sedimentary rocks traversed by many canyons. The Holbrook area has also been referred to as being a part of the Mogollon Plateau, the San Francisco Plateau, or the Arizona Plateau. The altitude at Heber, near the Mogollon Rim in the southern part of the area, is 6,484 feet; and at Holbrook, in the northern part of the area, it is 5,069 feet. As these two elevations indicate, the plateau slopes gently downward from the south toward the north. The northward slope of the land surface is practically the same as the dip of the underlying sedimentary formations.

1/ Harrell, M. A., and Eckel, E. B., Ground-water resources of the Holbrook region, Ariz.: U. S. Geol. Survey Water-Supply Paper 836-B, pl. 2, 1939.

Erosion has carried away the softer beds where they have not been protected by overlying lavas or by hard beds of sandstone or limestone. Thus the land surface is characterized by many mesas, buttes, and ridges, capped by the more resistant materials. The Little Colorado River crosses the area, flowing to the northwest. A cuesta or long ridge of rocks in the Moenkopi formation has been formed for many miles along the north bank of the Little Colorado River between Holbrook and Winslow. Silver Creek originates at the Silver Creek Spring and flows northward to join the Little Colorado River about 4 miles south of Woodruff. Chevelon Creek starts in the southwestern part of the area and flows northward to join the Little Colorado River between Joseph City and Winslow. Clear Creek has its origin southwest of the Holbrook area and flows northeastward to join the Little Colorado River east of Winslow. In many places the canyons cut by these three tributaries are impressive, being very narrow and having depths as great as 300 feet. In many places the rims of the canyons are level with the general land surface and no evidence of the canyon is visible until the brink is reached.

GEOLOGY AND ITS RELATION TO GROUND WATER

The rocks forming the outer crust of the earth are generally not entirely solid but contain numerous openings. The amount of water that can be stored in any rock depends upon the porosity of the rock, usually expressed as the percentage of the total volume of the rock that is occupied by voids. Porosity, however, determines only how much water a rock can hold, not how much it may yield to wells. The permeability of a rock may be defined as its capacity to transmit water under pressure. Beds of silt or clay may have a porosity as high or higher than that of beds of sand, sandstone, or gravel, but under ordinary hydraulic pressure silts and clays may be almost impermeable. A study of the geologic history of an area explains how the rocks were formed and placed in their present positions. As all these factors are of great importance in the occurrence of ground water, the geology of the area will be described, starting with the geologic history.

Geologic history

Permian period

The Supai formation is the oldest formation that will be discussed in this report. It does not crop out in the area, but strata penetrated by deep wells have been assigned to it. During Supai time northeastern Arizona was periodically covered by a sea that advanced and retreated. This sea came in from the southeast. During the period of maximum advancement the water was deep and clear and limestone was deposited. When the sea retreated to the southeast, leaving a flood plain, or when the water was shallow, silt, sands, and shales were deposited. These are usually red in color. Thus during these advances and retreats of the sea were formed the alternating layers of limestone, sandstone, and shale that are known as the Supai formation.

After the final withdrawal of the sea at the close of Supai time, a great thickness of light-colored sand was deposited over the greater part of the area. This white sand interfingered with the red-colored sediments at the edge of the sea. The sand was deposited to a thickness of many feet over hundreds of square miles. It is known as the Coconino sandstone and is the principal water-bearing bed of the area. The sand was deposited principally by wind action, although in places it was reworked by water and bears fossil imprints of animal tracks and raindrops.

The deposition of the Coconino sandstone was brought to a close when a sea gradually advanced across the area from the west. The Kaibab limestone, consisting of alternating layers of limestone and sandstone, was deposited in this sea. The northeastern limit of this sea was apparently near Holbrook, as the Kaibab limestone has not been recognized there. It is possible that the sandstones and limestones of the Kaibab were being deposited in the western part of the area at the same time that the Coconino sandstone was still being deposited in the eastern part of the area. After the sea withdrew, the area was exposed to a period of erosion that is represented by an unconformity at the base of the Triassic. It is probable that much of the Kaibab limestone was removed by erosion during this period.

Triassic period

The first sediments laid down during the Triassic were sands and silts of the Moenkopi formation which were deposited on a flood plain or in shallow bodies of water. Playa and lagoonal conditions also existed at this time and resulted in the deposition of salt and gypsum in some localities and in the accumulation of much fossil plant material in others. The water probably contained relatively small amounts of salts, as the fossils found are the type that lived in fresh water.

The next younger beds to be deposited in the area are known as the Shinarump conglomerate. The exact method of deposition of this conglomerate is unknown, although it contains fresh-water shells and fossil wood. At about this time volcanoes in or near the area erupted large quantities of volcanic ash. This was carried down by the streams and deposited to form great thicknesses of bentonitic clays which, with alternating beds of silt and sand, make up the Chinle formation. This formation was deposited partly in fresh water but mostly in shallow salt water and saline swamps.

Cretaceous period

Some time after the deposition of the Chinle formation and before the Cretaceous deposits were formed, the area was uplifted and tilted to the north and northeast, and intensive erosion took place. No record remains of any deposits that may have been formed in the area during this period of time. During the Cretaceous period, deposits of sands, silts, clays, and coal were laid down in the deep valleys formed by the previous erosion. These deposits are now exposed only in the extreme southern part of the area.

Tertiary period

Following deposition of the Cretaceous deposits tilting continued, more erosion took place, and during the Tertiary period and possibly part of the Quaternary the streams deposited sands and gravels in the major stream valleys. These sands and gravels cover a small part of the area near the Mogollon Rim. As indicated in the next paragraph, some volcanic rocks may have been formed in late Tertiary time.

Quaternary period

After another period of erosion, lavas of Quaternary or perhaps late Tertiary age were poured out from vents, principally along the southern edge of the area but also from scattered vents throughout the area. These lavas filled the existing valleys and in places completely covered the old land surface. The lavas lie unconformably upon the tilted and eroded surfaces of the older rocks. The lavas have had an important effect on the existing topography and on the courses of the streams. Since the lavas were deposited the streams have cut through them in places and have formed terrace deposits along their valleys in the lower part of the area.

Structure

During the Cretaceous and Tertiary periods the Colorado Plateau of Arizona was uplifted as a series of huge blocks, resulting in the formation of fault line scarps along the southern and western edges. The major part of the uplift occurred during the Tertiary period. The remnants of the scarps are known as the Mogollon Rim. The effect of the uplift has been to produce a plateau underlain by formations dipping about 30 feet per mile toward the north.

During the uplift gentle folds were formed. The largest is the Holbrook anticline, between Snowflake and Winslow. South of the Holbrook anticline is the Dry Lake syncline. Two minor anticlinal folds bring the Coconino sandstone near the surface at Holbrook and Penzance.

Geologic formations and their water-bearing properties

Supai formation (Permian)

The Supai formation does not crop out in the Holbrook area but rocks found in deep wells in the area have been assigned to the Supai. The thickness of the formation, as found in wells southwest of Holbrook, ranges from about 1,000 feet to about 1,300 feet. The formation consists principally of red shale and sandstone, with lenses and beds of limestone, salt, and gypsum. The nature of the formation indicates that it does not contain good water-bearing beds. The impermeable shales in the Supai formation are the lower confining beds for the overlying artesian aquifer, the Coconino sandstone. So far as known, all water encountered in wells in the Supai formation in the Holbrook area has been too salty to be of use.

Coconino sandstone (Permian)

The Coconino sandstone is exposed in a large area south and southwest of Holbrook and is also extensively exposed in the Mogollon Rim and in the canyons of Silver, Chevelon, and Clear Creeks. The formation ranges greatly in thickness, the greatest thickness being about 1,100 feet along the Mogollon Rim. The formation thins to the north and west and is missing in some places. Near Holbrook the formation ranges in thickness from 450 to 900 feet. The sandstone is generally buff to white but in places it is red or brown. It is cross-bedded and uniformly fine-grained, and it usually consists almost entirely of quartz. The upper part of the formation is much finer-grained than the lower part and carries much more siliceous cement, and it is almost impermeable. This cemented zone forms the cap over the formation that confines water in it under artesian pressure except where the cap has been fractured. Recharge to the Coconino sandstone in the Holbrook area occurs principally along the Mogollon Rim. Near the Mogollon Rim the Coconino is usually covered by the Kaibab limestone, by Cretaceous sands, or by lavas. However, all three of these rock formations absorb water readily from rains and stream flow and transmit some of this water through joints or solution channels to the underlying sandstone. The Coconino sandstone is the principal water-bearing bed in the Holbrook area and yields large supplies of water to some wells.

Kaibab limestone (Permian)

The Kaibab limestone is exposed in a large part of the area southwest of Holbrook (pl. 2). This formation is thickest to the south and west and thins rapidly toward the north and east. It has not been recognized in the vicinity of Holbrook, but near Heber it is about 200 feet thick. The Kaibab limestone consists mainly of white to gray limestone beds that are locally dolomitic and cherty. The more massive limestone beds alternate with thin shaldy and sandy beds. The Kaibab limestone is not an important aquifer in the area. The outcrop areas probably collect much water from rain and snow and from stream flow. A part of this water moves downward along joint plains and solution channels into the underlying Coconino sandstone, and a part is discharged through springs into the streams that cut through the formation.

Moenkopi formation (Triassic)

The Moenkopi formation is extensively exposed along the valley of the Little Colorado River in the Holbrook area. The largest area of exposure and the thickest section lies between Holbrook and the Petrified Forest. Numerous scattered remnants crop out south of the main outcrop area. The Moenkopi formation is probably from 200 to 400 feet thick in most of the Holbrook area, but it thickens to the northwest. It consists of a series of red to chocolate-brown shales and sandstones. Conglomerates and cross-bedded sandstones occur locally, and mud cracks and ripple marks are characteristic. The formation is not important as a source of water. It contains large amounts of salt and other readily soluble minerals and these cause the small amounts of water that are found in the formation to have a high mineral content, making the water unsatisfactory for domestic or irrigation purposes. Several stock wells obtain their water from this formation, however.

Shinarump conglomerate (Triassic)

The Shinarump conglomerate crops out in a narrow belt along the north side of the Little Colorado River. Small outcrops occur in a few places south of the river. The average thickness within the Holbrook area is probably less than 50 feet. The formation is usually gray in color. It contains coarse sand, beds and lenses of conglomerate, and petrified wood; and it characteristically forms cliffs and mesas. The formation cannot be considered a good aquifer, as there is little opportunity for it to receive or hold water. No springs or seeps were observed or reported in the Shinarump conglomerate in the Holbrook area.

Chinle formation (Triassic)

The Chinle formation is exposed in most of the area north and east of the Little Colorado River. Only the lower part of the formation is exposed in the Holbrook area. The maximum thickness in the area is about 700 feet. The Chinle formation consists of a series of variegated shales, sandstones, limestones, bentonite beds, and lenses of conglomerate. Petrified wood is abundant in several localities; the Petrified Forest National Monument contains the largest deposits. The Chinle formation is not important in the area as a source of water.

Upper Cretaceous rocks

Rocks of Upper Cretaceous age crop out in small areas along the southern boundary of the Holbrook area, and they probably underlie a part of the territory covered by the lava flows. These rocks consist principally of massive, cross-bedded, buff to green sandstone, interbedded with thin shales and coal seams. Some wells near Showlow derive water from the sandstones. Also, several springs derive their water from these sandstones.

Tertiary or Quaternary (?) sands and gravels

Sand and gravel deposits of Tertiary or Quaternary (?) age overlie the older formations in a small part of the area near the Mogollon Rim. The maximum thickness in the area is probably less than 30 feet. These sands and gravels take in water readily, and this water is either transmitted to the underlying formations or is discharged through seeps or springs along the edges of the deposits where the underlying formations are impermeable.

Quaternary or Tertiary (?) volcanic rocks

Basaltic lavas of Quaternary or possibly late Tertiary age are exposed in the southeast part of the Holbrook area. These volcanic rocks were poured out mainly from openings near the Mogollon Rim. The maximum thickness occurs where they fill old valleys and is several hundred feet. These flows are vesicular (contain gas-formed cavities) and are greatly fractured. They take in water readily and are excellent aquifers. Many springs and seeps occur at the contacts between the lavas and the underlying formations.

Quaternary alluvium

Alluvial deposits of unconsolidated silt, sand, and gravel partially fill many of the stream valleys of the area. These deposits are not shown on the geologic map (pl. 2). Their thickness is not great, and in most places it does not exceed 30 feet. These materials take in water readily from the streams, however, and they supply small amounts of water to many shallow dug wells in the Holbrook area. The wells are used for domestic and stock purposes.

GROUND-WATER RESOURCES

The most important water-bearing formation in the Holbrook area is the Coconino sandstone. It is the only formation that yields water in quantities sufficient for irrigation and it is the best source of supply for municipal, domestic, and stock wells. The water-producing possibilities of all the other formations are very limited, and these possibilities have been discussed in the geologic section. Therefore, the only formation that will be discussed under ground-water resources is the Coconino sandstone.

Occurrence

The lower part of the Coconino sandstone consists of an even-grained loosely-cemented quartz sand, and it is both highly porous and permeable. This sandstone is a very productive water-bearing material, and it is the source of most of the ground water used in the area. Water is found in the Coconino sandstone under artesian pressure along the Little Colorado River, and flowing wells can be obtained in several places along the river. Near the towns of Snowflake, Showlow, and Heber, the water in the Coconino sandstone is not under artesian pressure.

Source and movement

The Coconino sandstone is recharged principally in the highly elevated area of heavy rainfall along the Mogollon Rim. Water from rain and melting snow percolates into the sandstone in the outcrop areas. Some recharge occurs where the sandstone is exposed on the Holbrook anticline, between Snowflake and Winslow but, as this is an area of sparse rainfall, it is doubtful whether the amount of recharge is very great. Some water probably works its way into the Coconino sandstone through cracks in the overlying lavas and solution cavities in the Kaibab limestone.

The ground water in the Coconino sandstone moves in a general northeastern direction from the recharge areas toward the Little Colorado River, where it is discharged through seeps and flowing or pumped wells. The direction of ground-water movement is indicated by three features: (1) The pressure surface slopes to the northeast: (2) the Coconino sandstone dips in the same general direction; and (3) the dissolved-solids content of the water increases toward the northeast (pl. 1). Sufficient data were not available to determine the direction of movement of ground water through the sandstone north of the Little Colorado River.

Discharge

Discharge of ground water from the Coconino sandstone takes place in the following three ways: (1) Natural discharge at the surface from springs and seeps; (2) discharge from wells by natural flow and by pumping; and (3) underground leakage.

Natural discharge at surface

Artesian springs and seeps constitute one of the principal means of discharge of artesian water in the area. These springs and seeps occur in low places on the south side of the valley of the Little Colorado River and in the river channel. In these places the Coconino sandstone is exposed or is only thinly covered by younger formations. The water probably moves upward through fractures in the upper, impermeable part of the Coconino sandstone. The springs occur in several places along the Little Colorado River from Holbrook to the mouth of Chevelon Creek, the largest and most important occurring between Holbrook and Joseph City (see pl. 3). The springs and seeps along the south side of the Little Colorado River valley are characterized by large marshes. The water coming to the surface is lost by evaporation or transpiration or flows into the river. The presence of the artesian springs and seeps prompted the early settlers to drill for artesian water in or near the areas. It was not possible to determine during the present investigation how much of the 1,100 acres of marsh land was irrigated from the flowing wells and how much was sub-irrigated from natural seepage.

Discharge from wells

The largest discharge of ground water in the area is through flowing and non-flowing wells. The discharge from 24 flowing wells and 12 non-flowing wells was measured in 1946. Tables 1 and 2 contain records and logs of typical wells in the Holbrook area.

The yields of flowing wells range from less than 1 gallon a minute to 540 gallons a minute. The total discharge of the eight wells of the Joseph City Irrigation Company, which included the most productive flowing well in the area (well 7465, table 1), was 957 gallons a minute, measured in August 1946. This water flows into the Little Colorado River and is diverted for irrigation by a dam about 2 miles downstream, and it helps to irrigate about 1,600 acres of farm land near Joseph City. The flow from wells 5458 and 5489 is partially used to irrigate a small farm south of Joseph City.

The total discharge from flowing wells in the vicinity of Holbrook and Joseph City is about 2,300 gallons a minute, or about 3,700 acre-feet per year. The total discharge from the 12 non-flowing irrigation and municipal wells was about 600 acre-feet in 1946. The municipal supplies included are those of Holbrook and Joseph City. Thus the total measured discharge from the Coconino sandstone in the artesian area between Holbrook and Joseph City was about 4,300 acre-feet in 1946. In addition to the measured discharge, an undetermined amount of water is discharged in the seepage areas. A large part of the water discharged from the Coconino sandstone is wasted into the river and is not put to any beneficial use.

During the past few years, water for irrigation has been pumped from wells in the Coconino sandstone near the towns of Snowflake and Taylor. At present (1946) the development is on a small scale, but it is probable that the use of ground water for irrigation will increase in this area.

The municipal supplies for most towns in the Holbrook area and the domestic and stock supplies for most of the farms and ranches are also obtained from wells in the Coconino sandstone. The amount of water thus used has not been estimated, but it is probably small in comparison with the amount discharged in the Holbrook-Joseph City artesian area.

Underground leakage

Water is also discharged from the artesian water-bearing beds of the Coconino sandstone by upward leakage through the confining beds, and through abandoned and improperly-constructed wells. The upward leakage through confining beds in the Holbrook-Joseph City artesian area has been discussed in the section on natural discharge at the surface. Upward leakage probably occurs in other localities, but information is not available on them. The total amount of water discharged by underground leakage cannot be estimated, but it is probably considerable.

Fluctuation of ground-water levels

The hydrostatic level, or standing water level, of the artesian water at any point is the level to which the water will rise in a tightly-cased well drilled to the artesian reservoir. If the standing water level is above the land surface, the well will overflow at the surface. Several non-flowing wells near the flowing wells were measured periodically in order to determine the water-level fluctuations in the discharge area. During the 2½-year period in which the water levels in these wells have been measured, there has been no noticeable change in the water levels. Because the discharge from the Coconino sandstone has been uniform for several years, with no apparent decline in water levels, it is concluded that the safe annual yield in the Holbrook area has not been exceeded.

QUALITY OF WATER

By J. D. Hem

Chemical character of the ground water

In the 1946 study of ground water in the Holbrook area, 57 water samples from wells and springs in the county were analyzed, and 35 of these analyses are given in table 3. In addition, a few analyses were made of water samples from adjoining areas of Coconino County to the west. Results of a study in Apache County, which adjoins the Holbrook area on the east, were also correlated with the Navajo County analyses.

The report by Harrell and Eckel[2] contains analyses of a few samples of ground water in the area. A few of the sources that they sampled in 1933-34 were re-sampled in 1946. The results of this re-sampling showed that no significant changes in quality of water had occurred during the 12-year period.

The differences in chemical character of ground waters in the area generally result from the differences in the geologic formations from which the waters come. Although the quality of ground water in a single formation may differ from place to place, in this area the differences in quality from formation to formation are the most significant. This condition contrasts sharply with those in ground-water basins of southern Arizona, where the water-bearing formations in a given part of a basin usually yield waters of very similar chemical character and concentration, and the differences in quality of water from place to place within a basin are the most significant. Because of the close relation between quality of ground water and stratigraphy in the Holbrook area, the chemical character of the ground water in each of the principal water-bearing formations is discussed separately.

Coconino sandstone

The Coconino sandstone is the most important aquifer in the area, and more than half of the 57 samples analyzed came from this aquifer. In general, these waters contain moderate amounts of dissolved matter, usually ranging in concentration from 250 to about 750 parts per million of dissolved solids. Most of the dissolved matter in the dilute waters consists of calcium and bicarbonate. The more highly-mineralized waters contain greater amounts of sodium, sulfate, and chloride. Analysis 7472 (table 3) is typical of waters from the Coconino sandstone. In general, the dilute waters occur near the Mogollon Rim and concentrations increase northward toward the Little Colorado River.

Some wells in the area that are reported to obtain their water from the Coconino sandstone yield highly-mineralized water. These waters contain from 1,310 to 4,230 parts per million of dissolved solids, mostly sodium and chloride (common salt). The source of the salty water in these wells may be formations above the Coconino sandstone.

Moenkopi formation

Samples from 10 wells in the area represent water from the Moenkopi formation. This formation characteristically yields highly-mineralized water, containing mostly sodium and chloride. The dissolved solids of the 10 samples ranged from 1,770 parts per million in a sample from well 5655 to 87,300 parts per million in a sample from well 6051 (table 3). The most highly-concentrated waters from this formation were obtained from wells a few miles northeast of Holbrook.

Quaternary or Tertiary (?) volcanic rocks

In the southeastern part of the area a considerable number of wells and springs obtain water from porous volcanic rocks. Water from these rocks contains small to moderate amounts of dissolved matter, the dissolved solids in four samples of water ranging from 83 to 350 parts per million. Most of the dissolved matter in these waters consists of calcium, magnesium, and bicarbonate.

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[2] Harrell, M. A., and Eckel, E. B., Ground-water resources of the Holbrook region, Ariz.: U. S. Geol. Survey Water-Supply Paper 836-B, p. 89, 1939.

Quaternary alluvium

Ten samples were collected from wells in valley fill along the Little Colorado River and its tributaries within the Holbrook area. These samples indicate that water from valley fill in the area is moderately to rather highly mineralized, with a range in dissolved solids in the samples from 188 to 2,680 parts per million. The more dilute samples from the valley fill contained mostly calcium and bicarbonate, and the more highly-mineralized waters contained mostly sodium, sulfate, and chloride. The most dilute water sample from valley fill came from a well along a tributary south of the Little Colorado River near the Apache County line. The most concentrated water came from well 6252, in valley fill along the Rio Puerco (table 3). Most fill in the Little Colorado River Valley yields highly-mineralized water, but in some places leakage from the Coconino sandstone causes the water in the fill to be only moderately mineralized. Water in the fill along washes north of the river is usually highly mineralized.

Chemical character of surface water

A small amount of information is available regarding the chemical character of surface waters in the area. Samples were collected from the Little Colorado River at Woodruff for about 12 months in 1905-06 and at Holbrook for a short period in 1906 and the analyses were published by Stabler[3/]. These analyses may not be representative of water that passes these points under present conditions. A few more recent analyses are available for spot samples taken from the river and its tributaries during low-flow and flood periods. The available data are not sufficient to be conclusive, but they indicate that low-flow waters of the Little Colorado River are strongly influenced by surface inflows from tributary streams and by inflows of ground water. A few analyses of waters from low flows and flood flows in Silver Creek indicate that it carries water of low to moderate mineral content, containing mainly calcium, magnesium, and bicarbonate. Floods from areas where rocks of the Chinle or Moenkopi formations are exposed may consist of water containing large amounts of sodium, chloride, and sulfate derived from these formations. As a result of such flood inflows, flood waters of the Little Colorado River leaving the Holbrook area often are rather highly mineralized. These flood waters also carry considerable amounts of finely-divided sediment.

Relation of chemical character of water to use

Irrigation

Water from the Coconino sandstone is generally "excellent to good" for irrigation, and that from volcanic rock, in the southeastern part of the area, is all "excellent to good" for this purpose, according to the standards of Wilcox and Magistad[4/]. The highly-mineralized waters from Moenkopi formation and the highly-mineralized waters reported to be from

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3/ Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, 1911.

4/ Wilcox, L. V., and Magistad, O. C., Interpretation of analyses of irrigation waters and the relative tolerance of crop plants: U. S. Dept. Agr., Bur. Plant Industry, Soil and Agr. Research Administration, Riverside, Calif., (mimeographed), 8 pp., Mar. 1943.

the Coconino sandstone are generally "injurious to unsatisfactory" for irrigation. In a few places, water from the valley fill is "good to injurious" for irrigation, but in most areas the dissolved-solids content is high enough to make it "injurious to unsatisfactory."

In general, the only ground waters extensively used for irrigation in the area are those from the Coconino sandstone and from volcanic rocks. The more highly-mineralized waters in the area are generally available in such small quantities that they cannot be used extensively for irrigation.

Domestic use

Waters from the Coconino sandstone and from the volcanic rocks in the southeastern part of the area are the most likely to be satisfactory for domestic use. These waters are hard, but they all contain only moderate amounts of dissolved matter and less than 1.0 part per million of fluoride. Waters from other formations in the county are generally too highly mineralized to be satisfactory for domestic use.

Only two waters were found in the area that contained more than 1.5 parts per million of fluoride. Both these waters were rather highly mineralized and came from the valley fill. One of the samples was from well 2751, near Leroux Wash, and contained 1.9 parts per million of fluoride and the other was from well 6251, along the Rio Puerco, and contained 1.7 parts per million. From the available analyses, it appears that the ground waters of the Holbrook area are more nearly free from fluoride than those of most of Arizona.

Relation of quality of water to recharge and sources of dissolved matter in ground water

The analyses indicate that water in the Coconino sandstone is most dilute just north of the Mogollon Rim. A tongue of dilute water extends from the rim to the north and northeast between Woodruff and Hunt (pl. 1), indicating movement of ground water in that direction. The water apparently moves around the eastern end of the highest part of the Holbrook anticline and thence back northwest to the Little Colorado River, gradually increasing in dissolved-solids content. Ground waters in the Coconino sandstone near Holbrook and Joseph City generally have between 450 and 750 parts per million of dissolved solids. Ground water probably also moves around the western end of the anticline, but fewer analyses are available to indicate movement in this area.

Normally the water from the Coconino sandstone has a moderate dissolved solids content. However, two wells in Joseph City, two wells in Winslow, two wells north of the Holbrook anticline, and one well in the Dry Lake syncline have obtained highly-mineralized waters, reportedly from the Coconino sandstone. These highly-mineralized waters do not fit in with the pattern shown by the remaining 28 samples from the formation. It has not been established that the highly-mineralized waters found in these wells were actually obtained from the Coconino sandstone and it seems likely, in most instances, that the salty waters entered the wells from overlying Moenkopi deposits that had not been completely cased off. As water in the Moenkopi formation is highly mineralized, only a small amount of leakage around or through the casing would make the water pumped from a well entering the Coconino sandstone distinctly salty.

The most highly-mineralized water samples collected in the area were from the Moenkopi formation. This formation contains much soluble matter that was included at the time the beds were laid down, and as ground waters percolate through the beds the soluble matter goes into solution. The formation is variable in composition and therefore the waters in different localities and in different parts of the formation may differ in concentration.

The water from volcanic rocks in the area generally contains less dissolved matter than water from any other source. The volcanic rocks contain little soluble matter, and their open structure allows water to move through them with comparative rapidity, with little time for leaching. The more highly-mineralized waters from volcanic rocks probably came from the contact zone between the volcanic rocks and the impervious underlying rocks that contain soluble matter.

Probably the main source of recharge to the valley fill is stream flow. There is evidence to indicate that stream flow at times and in some tributaries may contain large amounts of dissolved matter. Also, some of the valley fill was derived from formations containing considerable amounts of soluble matter. Consequently, water in the valley fill may be expected to be highly mineralized in places. In some areas, however, local conditions may cause the water in this material to be of lower mineral content.

South of Joseph City, in the Obed marsh area, springs and seeps issuing from fill in the valley of the Little Colorado yield water very similar in chemical character to that from wells in the Coconino sandstone (see analyses 5459, 5460, 5463, and 5464, table 3). The springs and seeps are thus indicated to be the result of artesian leakage from the Coconino sandstone up through the overlying thin layers of the Moenkopi formation and valley fill.

SUMMARY AND CONCLUSIONS

The area included in this investigation is part of the Colorado Plateau and lies in Navajo County between the Mogollon Rim and the Navajo Indian Reservation. The ground-water studies were concerned primarily with the artesian area along the Little Colorado River between Holbrook and Joseph City.

The rocks exposed in the Holbrook area are mainly consolidated layers of sedimentary materials, ranging in age from Permian to Quaternary. These rocks include limestones, sandstone, clays, shales, and conglomerates, with minor amounts of interbedded gypsum and common salt. The sedimentary rocks are overlain by lava flows in the southeastern part of the area. Some of the rocks are permeable aquifers that serve as natural reservoirs or conduits for storing and transmitting water derived from rain and snow. The most important aquifer in the area is the Coconino sandstone, of Permian age, the oldest formation exposed in the area.

Water from rain and melting snow percolates into the Coconino sandstone where it is exposed at the surface, and some water moves into the formation through solution cavities and joints where the sandstone is overlain by limestone or by lava. Water moves through the sandstone in a generally northeast direction toward the Little Colorado River, where it is discharged through springs and flowing and pumped wells. The main area of discharge of ground water is south of the river, between Holbrook and Joseph City. There are 24 flowing and 12 non-flowing irrigation and municipal wells in this area. The total measured discharge in 1946 from these wells was about 4,300 acre-feet. An additional, undetermined amount of water was discharged by upward leakage through fracture zones. Because the discharge from the Coconino sandstone has been uniform for several years, with no apparent decline in water levels, it is concluded that the safe annual yield in the Holbrook area has not been exceeded.

Limited amounts of water are found in the sand and gravel underlying stream channels in the Holbrook area. There is generally sufficient water for stock and domestic use.

Ground waters from the Coconino sandstone are of fairly uniform quality and are considered "excellent to good" for irrigation. These waters are hard but are otherwise suitable for domestic use. Ground waters from the Moenkopi formation are unsatisfactory for irrigation and domestic use. In some localities these waters are used for stock. Ground waters from the valley fill are moderately to rather highly mineralized and are extensively used for domestic and stock purposes.

Chemical analyses indicate that a tongue of dilute water in the Coconino sandstone extends from near the Mogollon Rim to the north and northeast, between Woodruff and Hunt. This ground water moves around the eastern end of the Holbrook anticline and thence northwest toward Holbrook, gradually increasing in mineral content. Highly-mineralized water samples obtained from a few widely-spaced wells in the Coconino sandstone in the area indicate that salt water has entered these wells from the overlying Moenkopi formation through leaky casing.

Additional water can be obtained for irrigation in the area by: (1) Drilling and properly casing new wells; (2) tightly casing the existing wells; (3) installing adequate shut-off valves on all flowing wells; and (4) allowing wells to flow only when needed. In drilling new wells, the casings should be cemented from the top of the Coconino sandstone to the surface, or at least through formations containing salty water, to prevent upward leakage of water from the sandstone or downward leakage of salty water into the sandstone or into the wells. Corrosion of well casing would be prevented by such injection of cement between the casing and the wall of the well, through the overlying salt water-bearing formations. This is common oil-field practice.

The data presented in this report indicate that the Coconino sandstone in the Holbrook area has not been overdeveloped, although much water is now being wasted in non-beneficial use. New development should be undertaken cautiously, however, in order not to overdevelop the water supply of the Coconino sandstone. Careful records should be kept of the amount of water produced and of the water levels in wells, in order to determine more accurately the annual safe yield.

Table 1. - Records of typical wells, Holbrook area, Navajo County, Arizona
(All wells are drilled unless otherwise noted in "Remarks" column.)
(All wells obtain water from Coconino sandstone
unless otherwise noted in "Remarks" column.)

No.	Location	Owner	Driller	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
	T. 20 N., R. 19 E.					
d/ 2601	NW¼ sec. 32	Harvey Randall	-	5,082	121	8
	T. 20 N., R. 22 E.					
d/ 2751	sec. 9	W. B. Jeffers	-	5,340	35	-
	T. 19 N., R. 16 E.					
d/ 2852	SE¼SW¼ sec. 19	City of Winslow	F. Bentley	4,850	313	-
	T. 19 N., R. 15 E.					
2853	SW¼NE¼ sec. 27	R. R. Simon	-	-	280	6
	T. 18 N., R. 17 E.					
d/ 5051	NW¼NE¼ sec. 26	Geo. McLaws	-	-	-	9
	T. 18 N., R. 18 E.					
d/ 5252	NE¼SE¼ sec. 34	T. Ortega	-	-	-	8
d/ 5253	SE¼NW¼ sec. 35	W. R. Hunnicut	-	-	-	-
	T. 18 N., R. 19 E.					
5452	NE¼SW¼ sec. 16	Akin Smith	-	5,007	325	6
d/ 5453	NW¼SE¼ sec. 16	do.	F. Bentley	5,018	325	6
d/ 5454	cen. SW¼ sec. 17	J. L. Peterson	-	4,968	328	8
d/ 5455	SW¼NE¼ sec. 17	B. E. Newton	- Jeffers	4,995	120	5
d/ 5459	SW¼SW¼ sec. 28	L. S. Heward	F. Bentley	-	125	8

a/Measuring point was usually top of casing, top of pump base, or top of water pipe clamp.
b/C, cylinder; T, turbine, Cf, centrifugal; W, windmill; E, electric, G, gasoline,

Well records obtained by H. M. Babcock, C. T. Snyder, and G. E. Hazen

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
2601	-	-	C,W	S	62	Well 33-A in Water-Supply Paper 836-B. Water from valley fill.
2751	-	-	C,W	S	60	Driven well. Well 37 in Water-Supply Paper 836-B. Water from valley fill.
2852	e/ 13.5	July 1946	T,E	P	62	Measured discharge 490 gallons a minute. See log.
2853	164.9	Oct. 2, 1946	-	N	-	-
5051	Flowing	July 25, 1946	None	S	61	Measured flow 5½ gallons a minute, July 25, 1946.
5252	do.	do.	None	N	-	Reported flow 10 gallons a minute
5253	do.	do.	None	N	62	Seep in marsh. Estimated flow 3 gallons a minute.
5452	41.9	Oct. 2, 1946	None	N	-	Well 59 in Water-Supply Paper 836-B.
5453	30.6	do.	T,E	P	-	Reported discharge 80 gallons a minute. Owner reports leakage of mineralized water from formation above main aquifer. Well 60 in Water-Supply Paper 836-B. See log.
5454	0.6	June 8, 1946	Cf,G	D,I	61	Reported drawdown 5.5 feet, pumping 750 gallons a minute.
5455	-	-	C,G	D	64.5	Water from valley fill.
5459	Flowing	July 26, 1946	None	I	58	In Obed Marsh. Measured flow 440 gallons a minute. See log.

c/S, stock; P, public supply; D, domestic; I, irrigation; Ind., industrial; N, none.
d/See table 3 for analysis of water sample.
e/Water level reported.

Table 1. - Records of typical wells, Holbrook area, Navajo County, Arizona - Cont.

No.	Location	Owner	Driller	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
	T. 18 N., R. 19 E.					
d/ 5460	NW¼SE¼ sec. 35	W. R. Hunnicut	-	-	-	-
d/ 5463	SW¼NE¼ sec. 35	do.	-	-	-	4
d/ 5464	do.	do.	-	-	-	-
	T. 18 N., R. 20 E.					
d/ 5651	SE¼SW¼ sec. 14	C. A. Perkins	L. Cadwell	-	400	6
d/ 5652	SW¼SW¼ sec. 30	Ben Hunt	J. McLaws	-	145	10
5653	do.	do.	F. Bentley	-	160	12
5654	SE¼SE¼ sec. 32	do.	W. McLaws	-	-	8
d/ 5655	SE¼NE¼ sec. 33	C. A. Perkins	-	5,150	150	-
	T. 18 N., R. 22 E.					
d/ 6051	SW¼NW¼ sec. 18	U. S. Civil Aeronautics Auth.	-	5,250	275	8
	T. 18 N., R. 23 E.					
d/ 6251	SE¼NW¼ sec. 6	Richard Smith	-	5,254	95	-
d/ 6252	sec. 10	John Jones	-	5,258	60	3
	T. 17 N., R. 19 E.					
d/ 7251	sec. 33	S. Candelaria	F. Bentley	-	280	8
	T. 17 N., R. 20 E.					
7451	SW¼NW¼ sec. 1	E. B. Neuman	-	5,060	65	8
d/ 7452	NE¼NE¼ sec. 6	A.T. & S.F. R.R.	F. Bentley	5,070	90	-
d/ 7453	SW¼SE¼ sec. 6	A. Armijo	do.	5,048	100	-

Well records obtained by H. M. Babcock, C. T. Snyder, and G. E. Hazen

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
5460	Flowing	July 26, 1946	None	S	59	Seep in marsh. Estimated flow 5 gallons a minute.
5463	do.	July 25, 1946	None	S	62	In Obed Marsh. Reported flow 100 gallons a minute. Well 62 in Water-Supply Paper 836-B.
5464	do.	July 30, 1946	None	S	65	Seep in Obed Marsh. Estimated flow 400 gallons a minute.
5651	34.9	July 18, 1946	C,W	S	60	Reported discharge 5 gallons a minute.
5652	44.6	Oct. 2, 1946	T,E	I	62	-
5653	21.8	do.	T,E	D,S	-	-
5654	40.7	do.	C,W	S	-	-
5655	-	-	C,G	D,S	-	Water from Moenkopi formation.
6051	-	-	C,E	Ind.	63.5	Reported water too highly mineralized for domestic use. Water from Moenkopi formation.
6251	-	-	C,W	D	-	Water from valley fill.
6252	-	-	C,W	D,S	61	Driven well. Well 81 in Water Supply Paper 836-B. Water from valley fill.
7251	-	-	C,W	S	67	-
7451	5.7	Oct. 2, 1946	None	N	-	Drilled for stock use. Water from valley fill.
7452	-	-	C,W	Ind.	62	Railroad well at Penzance. See log.
7453	-	-	Cf,G	I	61	Measured discharge 217 gallons a minute.

Table 1. - Records of typical wells, Holbrook area, Navajo County, Arizona - Cont.

No.	Location	Owner	Driller	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
d/ 7465	NE¼NE¼ sec. 9	Joseph City Irr. Co.	F. Bentley	-	-	10
7470	NE¼SW¼ sec. 10	R. E. Whiting	-	-	-	6
7471	do.	do.	W. McLaws	5,075	-	18
d/ 7472	do.	City of Holbrook	do.	5,100	150	8
7478	SE¼SW¼ sec. 10	Geo. McLaws	F. Bentley	-	205	12
7489	NW¼SW¼ sec. 11	R. Henderson	do.	5,085	-	-
7493	SW¼NW¼ sec. 12	F. J. McLaws	-	5,112	-	12
	T. 17 N., R. 21 E.					
7651	SW¼SW¼ sec. 6	A. Armijo	W. McLaws	5,078	110	6
7652	do.	do.	-	do.	12	48
7653	NW¼NW¼ sec. 7	Ariz. Highway Dept.	W. McLaws	5,110	110	10
d/ 7654	SE¼NW¼ sec. 7	Roy Richards	P. Dindinger	5,100	-	6
7655	SW¼NW¼ sec. 10	John Hocho	F. Bentley	5,140	160	6
d/ 7656	SW¼SW¼ sec. 12	do.	do.	-	-	8
	T. 17 N., R. 22 E.					
d/ 7851	sec. 25	do.	-	-	400	-
	T. 16 N., R. 20 E.					
d/ 8501	NE¼NW¼ sec. 16	J. B. Jeffers	F. Bentley	5,455	450	8
	T. 16 N., R. 22 E.					
d/ 8604	sec. 17	L. Standitird	-	5,180	62	8
	T. 15 N., R. 21 E.					
d/ 8851	SE¼ sec. 8	J. M. Flake	-	-	400	8

Well records obtained by H. M. Babcock, C. T. Snyder, and G. E. Hazen

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
7465	Flowing	July 24, 1946	None	I	59	Measured flow 540 gallons a minute. Well 87 in Water-Supply Paper 836-B.
7470	31.1	Oct. 2, 1946	None	N	-	-
7471	5.6	do.	Cf,E	I	-	-
7472	-	-	T,E	P	62.5	Measured discharge 300 gallons a minute. Well 91 in Water-Supply Paper 836-B.
7478	52.2	Oct. 2, 1946	None	N	-	-
7489	13.8	do.	C,W	S	-	-
7493	55.3	Aug. 5, 1946	C,W	S	-	-
7651	14.4	Oct. 2, 1946	T,E	D	-	-
7652	8.7	do.	None	N	-	Dug well, 200 feet north from well 7651.
7653	40.2	Aug. 5, 1946	-	N	-	See log.
7654	56.8	Oct. 2, 1946	T,E	D	-	Estimated discharge 200 gallons a minute.
7655	51.9	Oct. 1, 1946	None	N	-	Water reported too highly mineralized for drinking.
7656	-	-	C,W	S	62	Water from Moenkopi formation.
7851	e/ 120	1933	C,W	S	65	Do.
8501	e/ 360	1946	C,E,W	S	62	Reported discharge 10 gallons a minute. See log.
8604	-	-	C,W	D	-	-
8851	e/ 290	1933	C,W	S	62	Well 111 in Water-Supply Paper 836-B.

Table 1. - Records of typical wells, Holbrook area, Navajo County, Arizona - Cont

No.	Location	Owner	Driller	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
	T. 14 N., R. 19 E.					
d/ 9026	sec. 7	Claude DeSpain	F. Bentley	5,825	430	8
	T. 13 N., R. 21 E.					
d/ 9304	NE¼ sec. 26	City Utilities Co.	W. McLaws	-	300	8
d/ 9305	SW¼SE¼ sec. 34	Logan Brimhall	Earl White	-	248	12
	T. 12 N., R. 16 E.					
d/ 9401	SE¼SW¼ sec. 13	Church of the Latter Day Saints	F. Bentley	6,440	423	-
	T. 12 N., R. 18 E.					
d/ 9451	SW¼SE¼ sec. 27	Sundown Boys Camp	do.	6,400	440	4

a/Measuring point was usually top of casing, top of pump base, or top of water pipe clamp.

b/C, cylinder; T, turbine, Cf, centrifugal; W, windmill; E, electric; G, gasoline.

Well records obtained by H. M. Babcock, C. T. Snyder, and G. E. Hazen

No.	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temp. °F.	Remarks
9026	e/ 405	-	C,G,W	S	61	Reported discharge 10 gallons a minute. Well 112 in Water-Supply Paper 836-B. See log.
9304	e/ 80	-	Cf,E	P	59	Snowflake town water supply. Reported discharge 500 gallons a minute.
9305	e/ 68	-	Cf,G	D,S,I	60	-
9401	e/ 397	-	C,E	P	57	Reported discharge 8 gallons a minute. See log.
9451	e/ 400	-	C,G	D,S	60	See log.

c/S, stock; P, public supply; D, domestic; I, irrigation; Ind. industrial; N, none.

d/See table 3 for analysis of water sample.

e/Water level reported.

Table 2. - Logs of typical wells, Holbrook area, Navajo County, Arizona.

	Thickness (feet)	Depth (feet)
Log of well 2852		
City of Winslow, owner.		
SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 19, T. 19 N., R. 15 E.		
Moenkopi formation		
Red shale	8	8
Red sandstone	14	22
Sandy red shale	10	32
Blue shale, $\frac{1}{2}$ gallon of water per minute	1	33
Kaibab limestone		
Sandy buff-colored limestone	3	36
Sandy gray limestone	15	51
Sandy white limestone	7	58
Water-bearing bed, $\frac{1}{2}$ gallon per minute	3	61
White limestone	1	62
Coconino sandstone		
White sandstone, water rose to 13 feet, 8 gallons per minute	3	65
White and buff-colored sandstone	140	205
Pink sandstone	15	220
Buff-colored sandstone, water rose to 13 feet, 45 gallons per minute	3	223
Pink sandstone	4	227
Buff-colored sandstone, water rose to 13 feet	27	254
White sandstone	8	262
Buff-colored sandstone	41	303
-	10	313
TOTAL DEPTH		313
Log of well 5453		
Akin Smith, owner.		
SE$\frac{1}{4}$ sec. 16, T. 18 N., R. 19 E.		
Topsoil	2	2
Sandy loam	3	5
Gravel	3	8
Sandy silt	9	17
Moenkopi formation		
Red and blue shale	30	47
Brown shale, water rose to 32 feet, 6 gallons per minute	5	52
Red and blue shale	33	85
Brown sandstone	11	96
Red and blue shale	36	132
Red shale	46	178
Red sandstone	10	188
Red shale, 24 gallons a minute of water	49	237
Red sandstone	14	251
Red shale	3	254
Kaibab limestone		
Yellow and blue shale	3	257
Coconino sandstone		
Sandstone	51	308
White sandstone, 5 gallons a minute of water	13	321
White sandstone	4	325
TOTAL DEPTH		325
Log of well 5459		
L. S. Heward, owner.		
SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 28, T. 18 N., R. 19 E.		
Quicksand and red silt	81	81
Moenkopi formation		
Red sandstone	5	86
Coconino sandstone		
White sandstone	32	118
Water-bearing white sandstone	7	125
TOTAL DEPTH		125

Table 2. - Logs of typical wells, Holbrook area, Navajo County, Arizona - Cont.

	Thickness (feet)	Depth (feet)
Log of well 7452		
A. T. & S. F. R. R., owner.		
NE¼NE¼ sec. 6, T. 17 N., R. 20 E.		
Sand and small gravel	21	21
Gravel, water seeping	5	26
Sandy red clay	6	32
Gravel and boulders, 1 gallon a minute of water	7	39
Pink sandstone, boulders, and silt, 10 gallons a minute of water	2	41
Brown sandstone	9	50
Boulders, sand and gravel	16	66
Coconino sandstone		
Yellow sandstone, 28 gallons a minute of water	14	80
TOTAL DEPTH		80
Log of well 7653		
Arizona Highway Dept., owner.		
NW¼NE¼ sec. 7, T. 17 N., R. 21 E.		
Moenkopi formation		
Red shale	4	4
Red sandstone	7	11
Coconino sandstone		
Yellow sandstone	42	53
White sandstone, 1 gallon a minute of water	4	57
Yellow sandstone	28	85
White sandstone, water rose to 38 feet	5	90
Yellow sandstone	13	103
-	7	110
TOTAL DEPTH		110

	Thickness (feet)	Depth (feet)
Log of well 8501		
W. B. Jeffers, owner.		
NE¼NW¼ sec. 16, T. 16 N., R. 20 E.		
Surface soil	2	2
Moenkopi formation		
Sandy red shale	32	34
Red shale	7	41
Kaibab limestone		
Sandy white limestone	6	47
Coconino sandstone		
Buff-colored sandstone	133	180
White sandstone	55	235
Buff, yellow, and gray sandstone, 1 gallon of water a minute	147	382
White sandstone	2	384
Buff-colored sandstone	38	422
White sandstone, water rose to 360 feet, 10 gallons a minute	7	429
Buff-colored sandstone	21	450
TOTAL DEPTH		450
Log of well 9026		
Claude DeSpain, owner.		
Sec. 7, T. 14 N., R. 19 E.		
Top soil and loose shale	35	35
Moenkopi formation		
Red shale	19	54
Red shale and sandstone	41	95
Kaibab limestone		
Limestone	30	125
Coconino sandstone		
White sandstone	295	420
Loose, white sandstone, water rose to 405 feet, 10 gallons a minute	10	430
TOTAL DEPTH		430

Table 2. - Logs of typical wells, Holbrook area, Navajo County, Arizona - Cont.

	Thickness (feet)	Depth (feet)
Log of well 9401		
Church of the Latter Day Saints, owner.		
SE¼SW¼ sec. 13, T. 12 N., R. 16 E.		
Boulders and soil	22	22
Coconino sandstone		
Limy sandstone	232	254
Sandstone	148	402
White sandstone, water rose to 397 feet, 8 gallons a minute	5	407
Buff-colored sandstone	16	423
TOTAL DEPTH		423
Log of well 9451		
Sundown Boys Camp, owner.		
SW¼SE¼ sec. 27, T. 12 N., R. 18 E.		
Surface soil and boulders	18	18
Moenkopi formation		
Yellow shale and sandstone	45	63
Red clay	11	74
Kaibab limestone		
Yellow shale and sandstone	61	135
Sandy, buff-colored limestone	55	190
Coconino sandstone		
Buff and yellow sandstone	215	405
Water-bearing white sandstone	4	409
Buff-colored sandstone	31	440
TOTAL DEPTH		440

Table 3. - Analyses of water from typical wells in Holbrook area, Navajo County, Arizona.
Numbers correspond to those in table 1 and plates 2 and 3.
Analyses by Geological Survey. (Parts per million except specific conductance)

Well No.	Date of collection, 1946	Depth (feet)	Specific conductance (Kx10[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
2601	June 7,	105	222	29	11	487	598	378	205	1.2	1.9	1430	118	90
2751	June 24,	35	149	6.2	3.2	373	748	180	22	1.9	2.1	957	28	97
2852	July 26,	313	727	110	70	1410	281	383	2120	-	.9	4230	562	84
5051	July 25,	-	418	88	48	753	266	301	1080	-	.6	2400	417	80
5252	do.	-	301	-	-	-	272	-	695	-	-	-	-	-
5253	July 30,	-	251	82	36	412	282	263	526	.3	.7	1460	352	-
5453	June 12,	328	285	66	31	508	237	170	725	.4	1.0	1620	292	79
5454	do.	328	124	43	27	184	238	129	204	.4	.3	705	218	65
5455	June 7,	120	240	58	22	457	346	377	390	.6	1.2	1480	235	81
5459	July 26,	125	115	52	31	145	242	119	177	-	.2	643	257	55
5460	do.	-	114	-	-	-	262	-	168	-	-	-	-	-
5463	July 25,	-	112	-	-	-	215	-	135	-	-	-	-	-
5464	July 30,	-	114	-	-	-	245	-	172	-	-	-	-	-
5651	July 18,	400	215	27	7.6	473	668	196	265	-	1.3	1310	98	91
5652	June 11,		222	112	53	290	206	281	470	.5	1.4	1330	498	56
5655	June 14,	40	309	132	56	443	217	307	725	.7	2.6	1770	560	63
6051	June 27,	275	10,000	13,200	1300	17,800	0	1140	53,800	-	-	87,300	38,300	50
6251	June 10,	95	173	9.5	3.2	408	636	184	145	1.7	2.7	1070	36	96
6252	do.	60	428	36	16	949	650	496	825	.6	6.3	2680	156	93
7251	June 18,	280	295	66	38	526	242	328	655	-	1.9	1730	320	78
7452	July 15,	80	104	-	-	-	201	-	145	.3	-	-	-	-
7453	July 25,	100	111	-	-	-	214	-	164	-	-	-	-	-
7465	July 24,	-	72.9	-	-	-	194	-	68	-	-	-	-	-
7472	June 7,	150	75.7	48	34	60	206	133	56	.3	.4	433	260	33
7654	July 3,	-	229	-	-	-	234	-	510	.1	-	-	-	-
7656	July 22,	-	628	186	54	1110	213	339	1830	-	.7	3620	686	78

Table 3. - Analyses of water from typical wells in Holbrook area, Navajo County, Arizona - Cont.

Well No.	Date of collection, 1946	Depth (feet)	Specific conductance (Kx10^5 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
7851	June 14,	400	1070	169	51	2250	320	305	3500	.6	-	6430	631	89
8501	June 13,	450	113	68	40	115	308	120	146	.1	.6	641	334	43
8604	do.	62	105	96	35	88	268	214	92	.3	2.4	660	348	33
8851	June 11,	400	110	71	28	121	260	110	160	.3	1.1	620	292	47
9026	June 25,	430	267	231	50	262	189	312	615	-	7.0	1570	782	42
9304	July 19,	300	56.6	66	24	26	305	46	13	.2	2.7	328	263	18
9305	July 2,	248	50.6	52	27	21	278	47	6	-	2.1	292	240	16
9401	do.	423	41.6	-	-	-	224	-	17	.0	-	-	-	-
9451	do.	440	40.9	-	-	-	242	-	5	.0	-	-	-	-

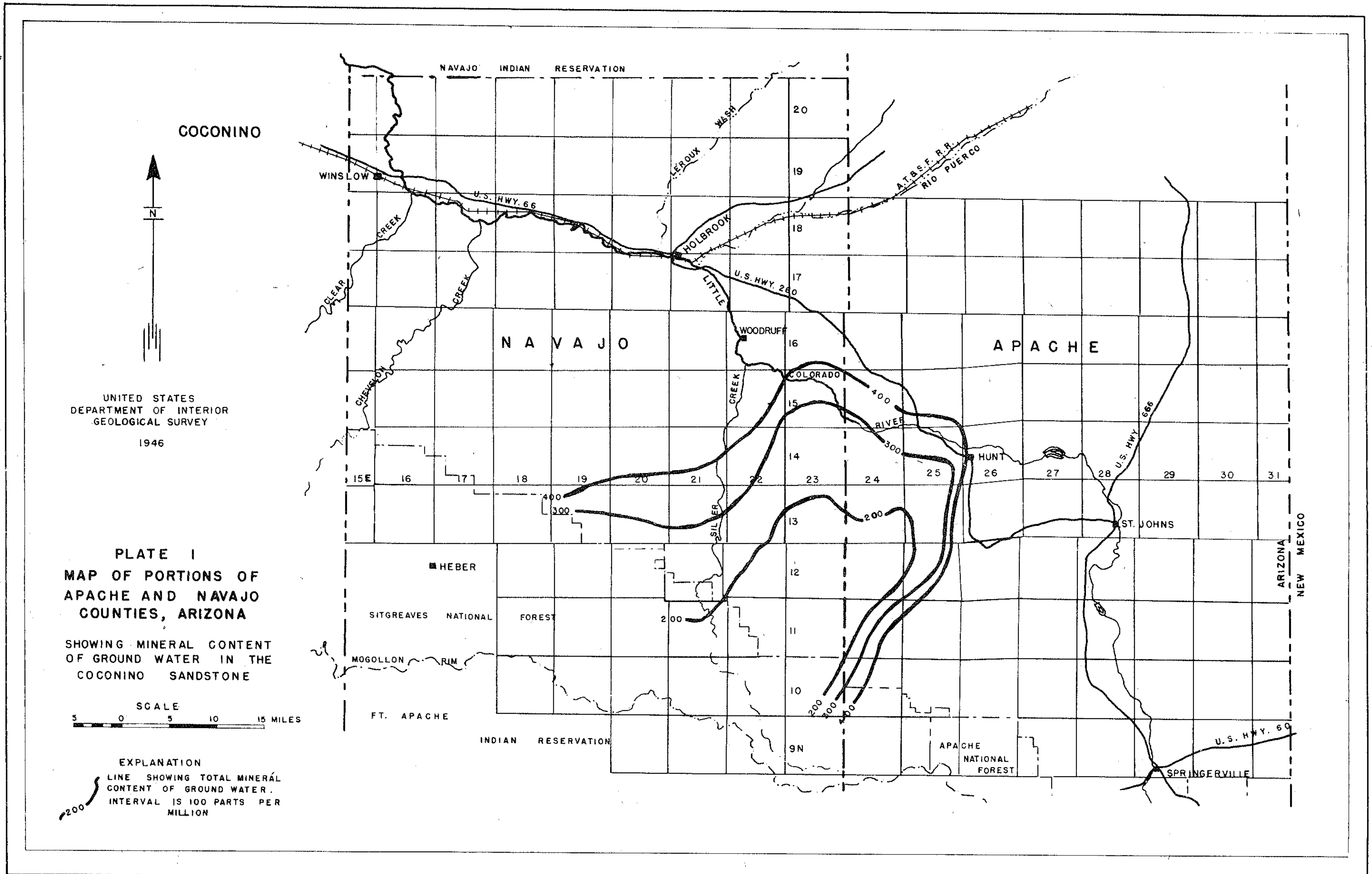


PLATE I
MAP OF PORTIONS OF APACHE AND NAVAJO COUNTIES, ARIZONA
SHOWING MINERAL CONTENT OF GROUND WATER IN THE COCONINO SANDSTONE

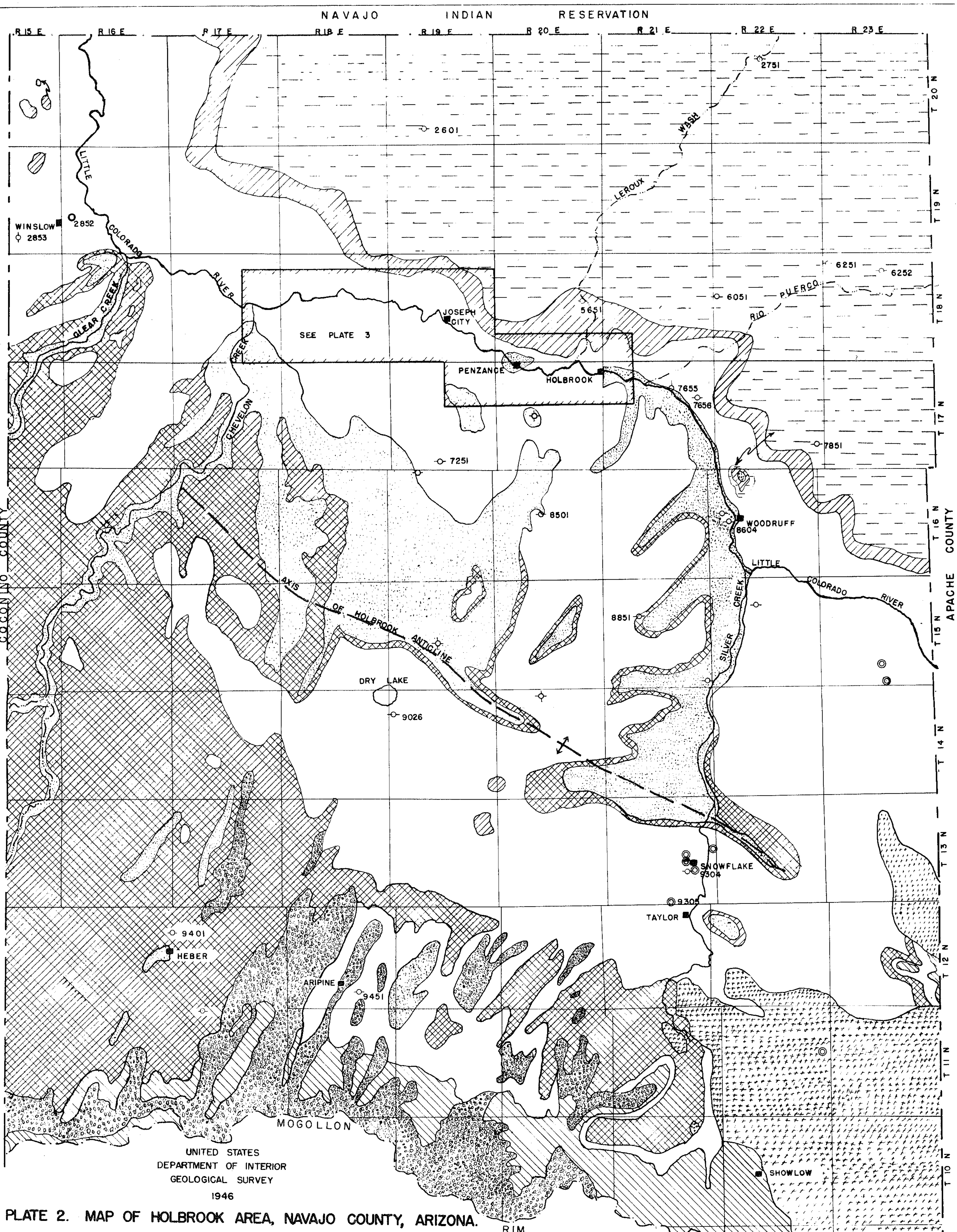


PLATE 2. MAP OF HOLBROOK AREA, NAVAJO COUNTY, ARIZONA.

SHOWING GEOLOGY AND LOCATIONS OF WELLS

SCALE

6 0 6 12 MILES

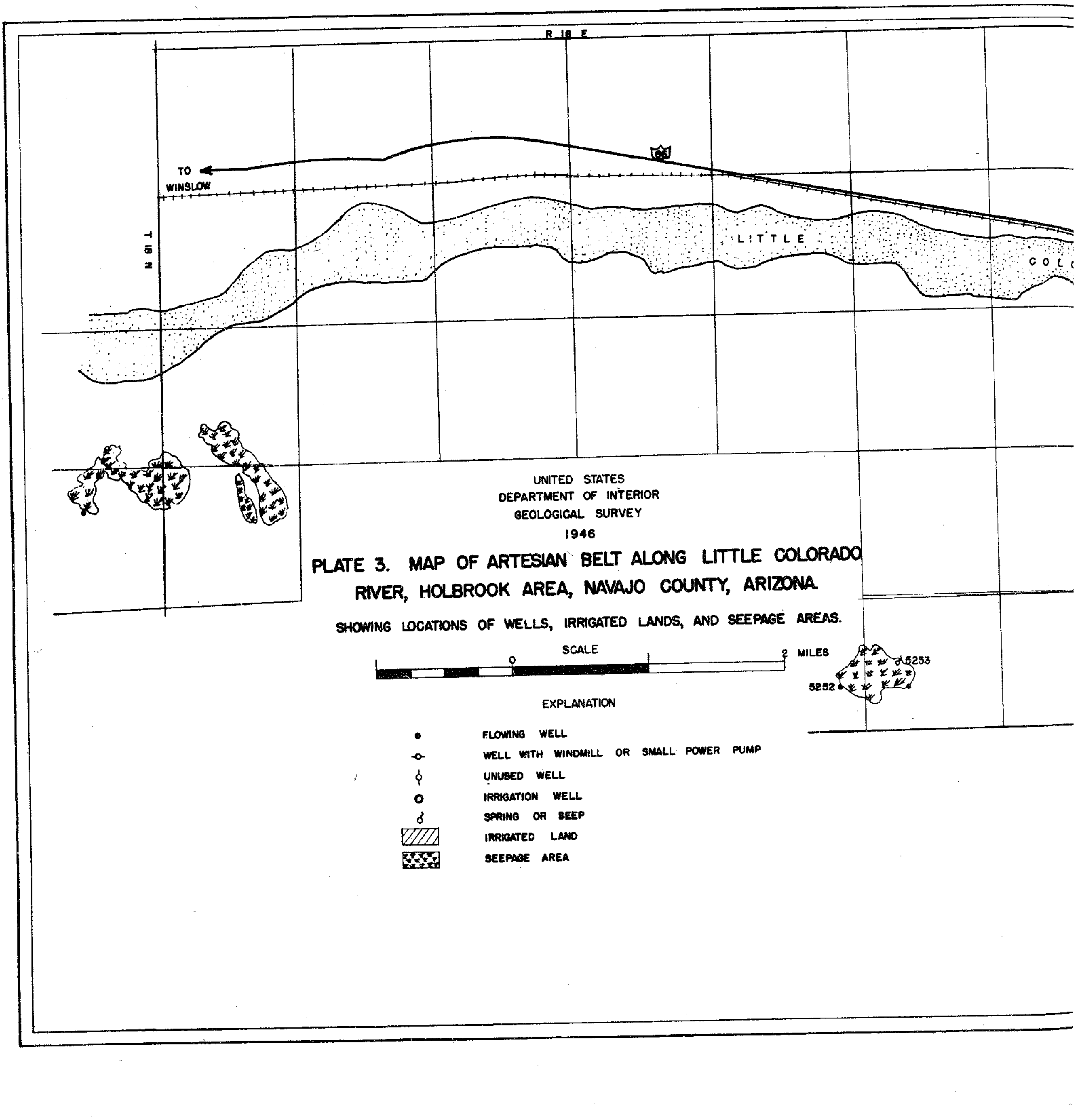
EXPLANATION

FORMATION OR MATERIAL	PROBABLE AGE	WATER-BEARING PROPERTIES
VOLCANIC ROCKS	QUATERNARY OR TERTIARY (?)	YIELDS WATER TO WELLS AND SPRINGS FROM FRACTURE ZONES.
SAND AND GRAVEL	TERTIARY OR QUATERNARY (?)	YIELDS WATER TO WELLS AND SPRINGS IN LOCAL AREAS.
SANDSTONE, COAL, AND SHALE	CRETACEOUS	YIELDS WATER TO WELLS AND SPRINGS IN LOCAL AREAS.
CHINLE FORMATION	TRIASSIC	NOT AN IMPORTANT AQUIFER IN AREA.
SHINARUMP CONGLOMERATE	TRIASSIC	NOT AN IMPORTANT AQUIFER IN AREA.
MOENKOPI FORMATION	TRIASSIC	YIELDS LIMITED AMOUNTS OF MINERALIZED WATER.
KAIBAB FORMATION	PERMIAN	NOT AN IMPORTANT AQUIFER IN AREA.
COCONINO SANDSTONE	PERMIAN	PRINCIPAL WATER-BEARING FORMATION IN AREA. WATER UNDER ARTESIAN PRESSURE IN PLACES.

- WELL WITH WINDMILL OR SMALL POWER PUMP
- IRRIGATION OR MUNICIPAL WELL
- UNUSED WELL
- OIL TEST

GEOLOGY AFTER M. A. HARRELL AND E. B. ECKEL

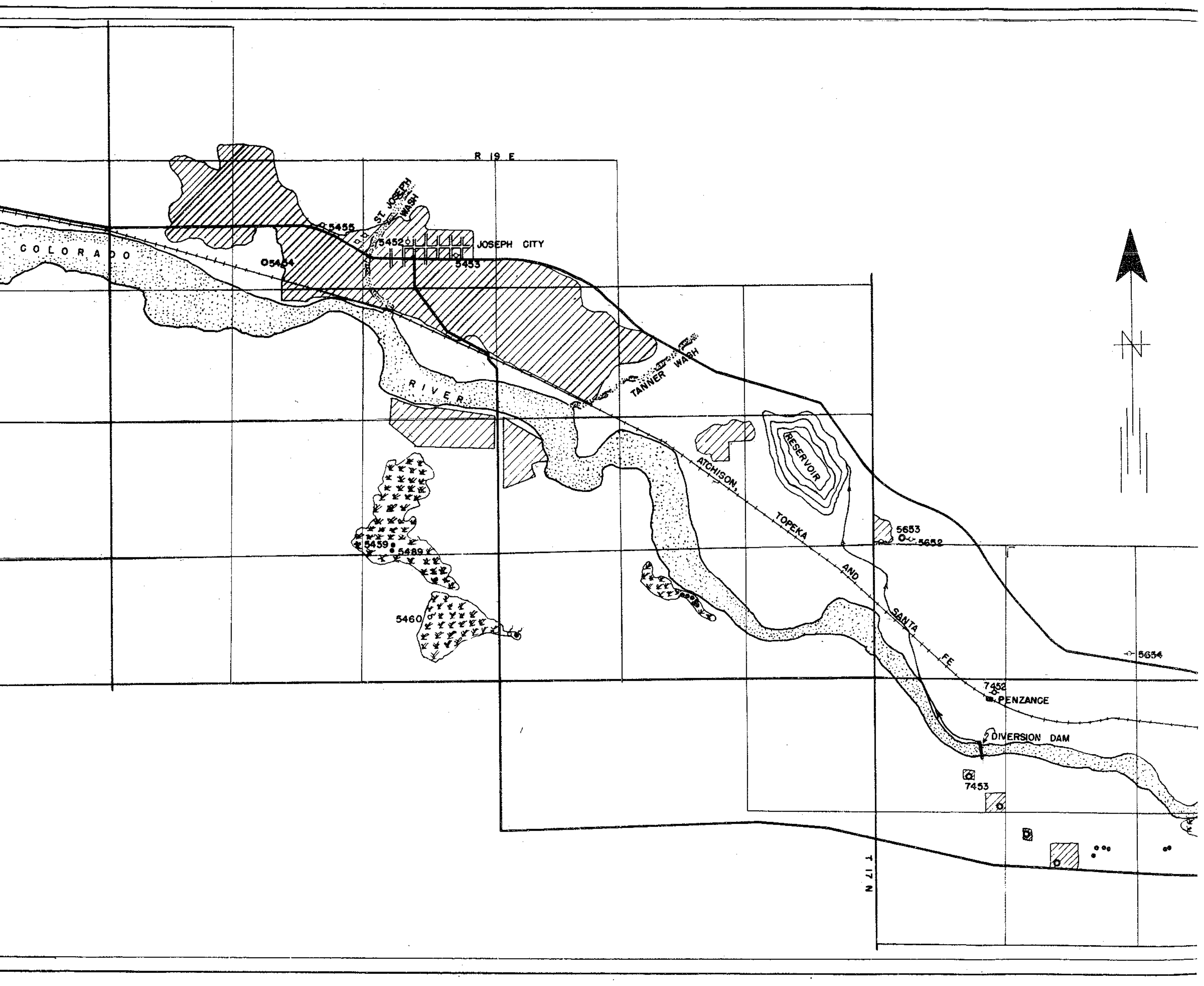
JPM
12511



UNITED STATES
DEPARTMENT OF INTERIOR
GEOLOGICAL SURVEY
1946

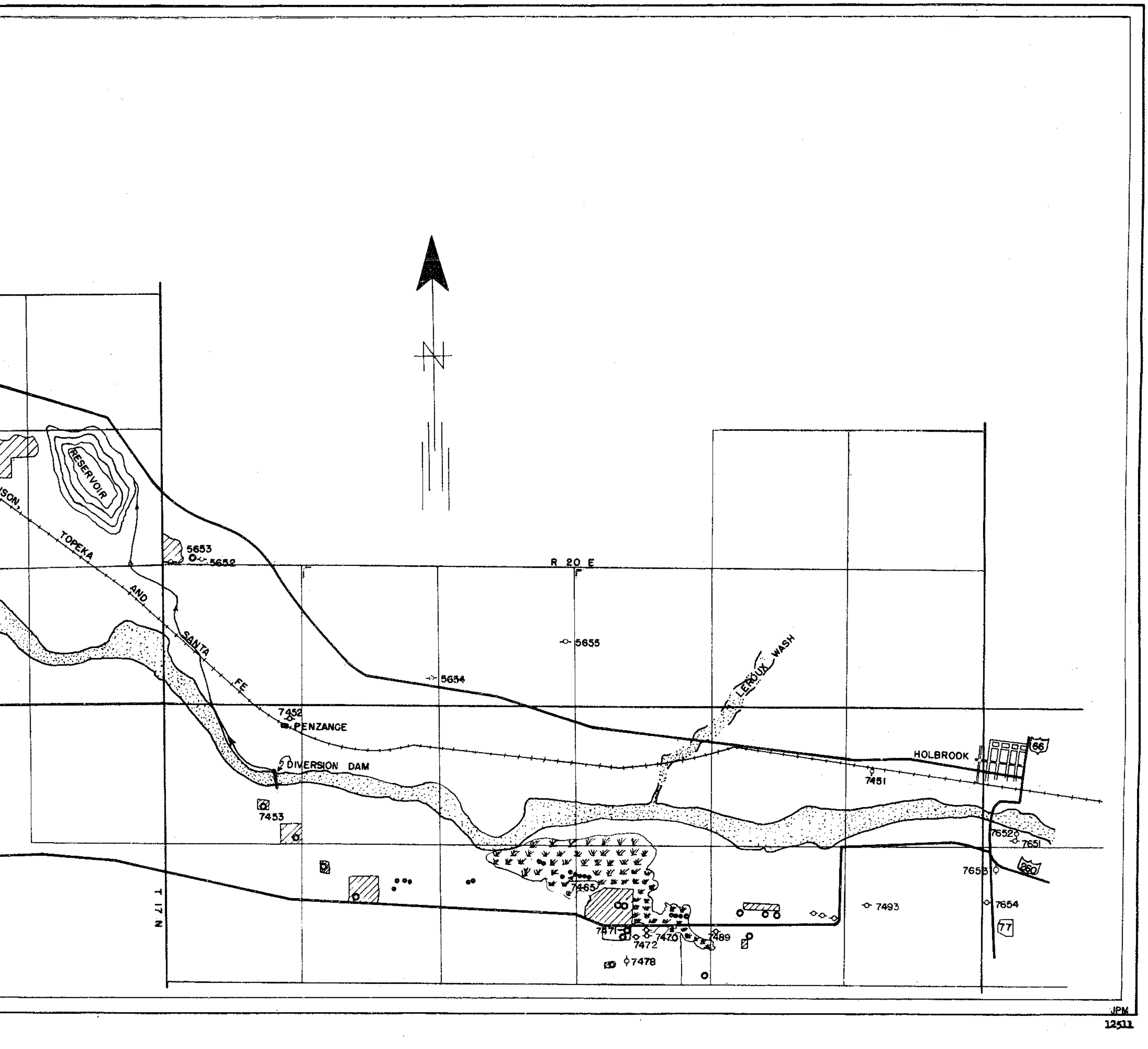
PLATE 3. MAP OF ARTESIAN BELT ALONG LITTLE COLORADO RIVER, HOLBROOK AREA, NAVAJO COUNTY, ARIZONA.

SHOWING LOCATIONS OF WELLS, IRRIGATED LANDS, AND SEEPAGE AREAS.



R 19 E
ST. JOSEPH WASH
JOSEPH CITY
COLORADO
RIVER
TANNER WASH
RESERVOIR
ATCHISON, TOPEKA AND SANTA FE
PENZANCE
DIVERSION DAM
T 17 N
N
5455
5452
5453
5454
5459
5489
5460
5653
5652
5654
7452
7453

Plate 13


RESERVOIR
TOPEKA
AND
SANTA
FE
5653
5652
R 20 E
5655
5654
LEROUX WASH
7452
PENZANCE
DIVERSION DAM
HOLBROOK
66
7451
7453
7465
7493
7471
7472
7470
7489
7478
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260
77
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