5G24

United States
Department of the Interior
Geological Survey

Preliminary report on the ground-water resources of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah

By
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Based on data collected by J. W. Harshbarger, H. A. Whitcomb, C. A. Repenning, R. L. Jackson J. T. Callahan, S. C. Brown, the author, and others

Holbrook, Arizona
August 1951

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PRELIMINARY REPORT ON THE GROUND-WATER RESOURCES OF THE NAVAJO AND HOPI INDIAN RESERVATION, ARIZONA, NEW MEXICO, AND UTAH

By L. C. Halpenny

Based on data collected by J. W. Harshbarger
H. A. Whitcomb, C. A. Repenning, R. L. Jackson
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ABSTRACT

The Ground Water Branch of the United States Geological Survey is now engaged in a reconnaissance of the ground-water resources and geology of the Navajo country, which lies in northeastern Arizona, northwestern New Mexico, and southeastern Utah. The work is being financed by the Office of Indian Affairs.

The occurrence of ground water in the region is dependent on the dominant factors of topography and climate. The topography of the Navajo country is one of sharp relief, with deep canyons and high mesas and buttes. Runoff is rapid, and in many places there is little opportunity for rain and melting snow to percolate into the ground. The climate is arid and is characterized by extremes of temperature and rainfall. The average percipitation is 10 inches per year, and much of this falls during torrential storms in the summer months.

The inadequate water supply of the region has a dominating effect on the economy. Sheep raising is the principal occupation, as much of the grazing lands are considered too poor for cattle. Water holes are few.

The principal aquifers of the region are the Permian sandstones, the Triassic Shinarump conglomerate, the Jurassic (?) Navajo sandstone, the Jurassic Cow Springs sandstone, the Cretaceous Dakota sandstone, and the sandstone members of the Cretaceous Mesaverde formation. Quaternary alluvium yields water to wells in some places, but in most places these supplies are subject to failure in time of drought.

Many more wells can be drilled for livestock and domestic use without overdeveloping the principal aquifers. There is little chance for developing ground-water supplies for irrigation, however, except from the alluvium in places where recharge is abundant.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The Ground Water Branch of the United States Geological Survey is now engaged in a reconnaissance of the ground-water resources and geology of the region generally known as the Navajo country, which lies in northeastern Arizona, northwestern New Mexico, and southeastern Utah. The work is being done at the request of the Office of Indian Affairs and is financed by that office. The purpose of the work is twofold; To aid the Indian Office currently in locating and developing ground-water supplies for livestock, domestic, and community use; and to prepare a comprehensive report on the ground-water resources and geology of the region, which will serve as a guide to further development and utilization of the available water supply.

The investigation is under the general supervision of A. N. Sayre, geologist in charge of the Ground Water Branch of the Geological Survey, and under the direct supervision of the author of this report. The work has been aided by review and consultation with the heads of the district offices in Arizona, New Mexico, and Utah: Messrs. S. F. Turner, C. V. Theis, and H. E. Thomas.

LOCATION

The Navajo country includes the area occupied by the Navajo and Hopi Indian Reservations, and comprises some 16,000,000 acres or about 25,000 square miles. Most of the region is in Arizona (see pl. 1). Roads within the region are mostly dirt; a few have been gravelled in recent years, but no paved roads exist except along the borders of the reservations. U. S. Highway 89 crosses the western side, U. S. Highway 66 lies along the southern side, and U. S. Highway 666 crosses the eastern side. The A. T. & S. F. Railroad parallels U. S. Highway 66 along the southern border of the region.

There are no incorporated towns on the Navajo and Hopi Reservations. The communities are mostly government owned, and were constructed to provide schools, hospitals, and other services for the Indians. Trading post at most of the places shown on plate 1 supply the residents with the necessities of life, and the supplies are brought in by truck. Gallup and Farmington, N. Mex., and Holbrook, Winslow, and Flagstaff, Ariz., are the trade centers for the region.

PREVIOUS INVESTIGATIONS

Prior to beginning the regional investigation on October 20, 1950, the Ground Water Branch had been working on a limited scale in the region since January 1948, assisting the Indian Office in locating and developing ground-water supplies. All the data collected during that period will be incorporated in the final report.

From 1942 to 1948 the Technical Coordination Branch of the Water Resources Division, Geological Survey, furnished occasional assistance in selecting sites for water wells. H. V. Peterson, geologist, was in charge of this work.

From 1934 to 1940 the Soil Conservation Service, Department of Agriculture, compiled well records, furnished geologic information, and generally aided the Indian Office in developing ground-water supplies in the region.

In 1916 the Geological Survey published Water-Supply paper 380, "The Navajo Country - A geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah", by H. E. Gregory. This is the most comprehensive report available on the ground-water resources of the region.

ACKNOWLEDGMENTS

The writer is greatly indebted to many officials of the Office of Indian Affairs for their cooperation and assistance. Many thanks are especially due to Messrs. J. J. Schwarz, C. Wilson, and L. Kingsley for their guidance in the field and helpful discussion of problems.

The close cooperation and prompt assistance rendered by the Southwestern Laboratory of the Quality of Water Branch, Albuquerque, N. Mex., is gratefully acknowledged. Particular thanks are due to J. D. Hem, District Chemist, for his aid in defining quality-of-water problems.

GENERAL FEATURES OF THE REGION

TOPOGRAPHY

The Navajo country is a part of the physiographic province known as the Colorado Plateau, an elevated area occupying parts of Utah, Arizona, Colorado, and New Mexico. The New Mexico portion of the Navajo country is a part of the San Juan Basin, and the Arizona portion comprises the Black Mesa Basin.

The region lies within the drainage basin of the Colorado River, and the principal tributaries, in the Navajo country, are the San Juan, Chaco, Puerco, and Little Colorado Rivers. In the western part of the region, deep canyons have been cut by the San Juan, Little Colorado, and Colorado Rivers as much as 3,000 feet below the prevailing land surface.

The altitude in the Navajo country ranges from about 2,800 feet, at the mouth of the Little Colorado River, to 10,416 feet, at the top of Navajo Mountain (see pl. 1). The mean altitude of the region is about 5,500 feet, with only 156 square miles below 4,000 feet and only 42 square miles above 9,000 feet (Gregory, 1917, p. 11).

Mesas, buttes, and canyons are the primary topographic features of the Navajo country. Erosion resulting from the strong winds and from occasional torrential rains has produced a landscape that is sharply angular in appearance.

CLIMATE

The climate of the Navajo country is one of extremes, both of temperature and precipitation. The summers are hot and the winters are cold; long dry spells are punctuated by intense storms of short duration. Mean annual temperature is of the order of 55° F., with extremes ranging from 105° F. downward to -20° F. Mean precipitation is about 10 inches a year. The precipitation is greater than the mean on the Chuska and Carrizo Mountains, Navajo Mountain, and Black Mesa. Precipitation on the western part of the Navajo Reservation averages about 6½ inches a year.

Rainfall varies widely from one year to another. Occasional wet years are succeeded by dry years, and some drought periods last for several years. The average rainfall at 11 selected stations in the Arizona portion of the region is 9.22 inches per year. During the 5 years 1946-50 inclusive, average precipitation was as follows: 1946, 8.64 inches; 1947, 9.35 inches; 1948 7.94 inches; 1949, 9.53 inches; and 1950. 4.46 inches. The drought that began in the fall of 1949 has not abated as of July 1, 1951. Records from the 11 stations were available through April, 1951, and these records indicate that the cumulative deficiency in precipitation from January 1, 1949, to May 1, 1951, was 5.28 inches.

ECONOMY OF THE REGION AS AFFECTED BY WATER SUPPLIES

The ground-water supplies of the Navajo country are profoundly affected by the dominating factors of topography and climate. Stream channels have steep gradients, runoff is rapid, and consequently there

is little opportunity for precipitation to percolate into the ground. Locally, water that may have entered the ground emerges deep in inaccessable canyons from rock strata which in other regions might be satisfactory aquifers. Water that has percolated into the ground on some mesas is returned to the land surface by seepage along the base.

The climate of the region also has an effect upon the ground-water supplies. Summer rains are of the torrential type, and most of the precipitation runs off without adequate opportunity to enter the ground. Recharge from winter storms and from snow-melt is greater than from summer rains, but the total annual precipitation is small and therefore the total recharge is small.

The inadequate water supply of the region is reflected in the type of vegetation. Range lands are poor owing to the inadequate rainfall, and most of the land is considered unsuitable for raising cattle. Sheep raising is the principal industry of the region, and even this a marginal undertaking. Water holes are few and the sheep frequently have to be herded 8 to 10 miles to water. Overgrazing in the vicinity of water holes is common, resulting in a tendency to increase erosion. In a few remote areas where grass is of better than average quality, water for livestock is unavailable.

Irrigation by diversion of water from streams is being practiced in some parts of the region. The largest potential irrigation project is south of Shiprock, with proposed diversion of water from the San Juan River. A dam on Chinle Wash near Many Farms, in the central part of the Reservation, furnishes water for a small irrigation project. Similar small-scale irrigation projects are at Moenkopi, Ganado, and Tohatchi. Near Tohatchi, flowing wells yield sufficient water for irrigating a small acreage. Generally there is little hope for extensive irrigation from ground-water supplies.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Stratigraphic relations in the Navajo country are difficult to determine, and in many cases the same formation or equivalent stratigraphic units have different names at different places. At the time this paper was written the geologic field work was far from complete. The following discussion of the geology of the Navajo country is highly generalized and is intended only as a background for the description of the ground-water resources of the region. Information available on the quality of water obtainable from the different formations is not complete and has not been fully analyzed at the present stage of investigations.

STRATIGRAPHY

Paleozoic rocks

Rocks of the Permian, the Pennsylvanian (?), and the Mississippian systems crop out in the walls of the canyons of the Colorado River and the Little Colorado River, at the extreme western edge of the Navajo country. Rocks of the upper part of the Permian crop out in small areas throughout the eastern half of the region. Only the upper 200 to 800 feet of the Permian rocks have economic value as sources of ground water in the Navajo country.

The largest source of water in the region that is available from rocks older than Permian is Blue Springs, which issues from the Mississippian Redwall limestone in the bottom of a 2,200-foot canyon along the Little Colorado River about 13 miles upstream from its confluence with the Colorado River. This spring flows about 90,000 gallons per minute, but the water is inaccessible for use by the Indians and is of poor quality.

Permian system

Permian sandstone, overlain by Permian limestone, crops out in the southwest part of the region in the vicinity of Cameron, and west of U. S. Highway 89 near Cedar Ridge. This sandstone is known as the Coconino sandstone and the overlying limestone as the Kaibab limestone. In Monument Valley, and in Canyon DeChelly, a sandstone of approximately equivalent age is referred to as the DeChelly sandstone member of the Cutler formation. Southeast of Gallup, N. Mex., in the Zuni Mountains the sandstone and overlying limestone are known collectively as the San Andres formation and individually as the Glorieta sandstone member and the limestone member. These Permian rocks underlie a large part of the Navajo country.

The Permian sandstones of the region are water-bearing in most places. However, in many places they lie too deep beneath the land surface to be within economic drilling and pumping limits, and in other localities the water they contain is of unsuitable quality for domestic use. Wells that yield water from the Coconino sandstone have been drilled in the Navajo Reservation at Pine Springs, Klagetoh, Ganado, St. Michaels, and near Cameron and Leupp. In the Fort Wingate, N. Mex., area, wells yield water from both the limestone member and the Glorieta sandstone member of the San Andres formation. In the Navajo country, these Permian sandstones generally are clean and well sorted and relatively free of cementation, thus allowing free movement of water both vertically and laterally.

Mesozoic rocks

Triassic system

Moenkopi formation. - The lowermost strata of Triassic age that occur in the Navajo country comprise the Moenkopi formation, an assemblage of siltstone, claystone, and sandstone beds that lie unconformably on the Permian rocks. The thickness ranges from a few feet to more than 400 feet. The Moenkopi formation crops out in a belt paralleling the Little Colorado River downstream to Cameron and thence north near U. S. Highway 89 to Lee's Ferry. Rocks of the Moenkopi formation also are exposed in Monument Valley. The Moenkopi crops out along U. S. Highway 66 a few miles east of Sanders, Ariz. It is believed that the Moenkopi formation underlies most of the Arizona portion of the region.

The Moenkopi formation has no value as an aquifer in the Navajo country because the quantities obtainable are small and the high mineral content makes the water unfit even for livestock use.

Shinarump conglomerate. - The Shinarump conglomerate unconformably overlies the Moenkopi formation in most parts of the region, and where the Moenkopi is not present, it lies on Permian rocks. The Shinarump conglomerate is composed of rounded pebbles and gravels, fragments of

petrified wood, sandstone, siltstone, and claystone. It is believed that the formation is the introductory phase of the sedimentary sequence that includes also the Chinle formation. In the Navajo country the thickness ranges from about 30 feet to over 150 feet. The Shinarump conglomerate crops out in a belt along the Little Colorado River to Cameron, thence north along U. S. Highway 89 to Lee's Ferry. The formation caps the monuments in Monument Valley, and crops out in a belt southward along the Defiance uplift from Round Rock to U. S. Highway 66. Another area of exposures lies along the northern flank of the Zuni Mountains.

The water-bearing properties of the Shinarump conglomerate are favorable. Wells that tap the Shinarump conglomerate have been drilled in Black Creek Valley, along U. S. Highway 66 east of Gallup, northeast of Chinle, and along the southern and southwestern margins of the Navajo Indian Reservation.

Chinle formation. - The Chinle formation conformably overlies the Shinarump conglomerate. In the Navajo country the formation is divisible into three members; a lower member composed mostly of siltstone and sandstone beds; a middle member that is predominately claystone but in the eastern part of the region contains sandstone beds; and an upper member that comprises alternating beds of siliceous limestone and siltstone. An irregular erosional unconformity a few feet above the top of the uppermost limestone is considered to be the upper boundary of the formation. This position nearly coincides with the top of the "B" member of the Chinle formation as described by Gregory (1917, p. 42). The Chinle formation crops out over a large part of the Navajo country; the thickness ranging from about 900 feet to over 1,400 feet. Along the southern and southwestern sides of the region the formation is exposed in a belt many miles wide forming the Painted Desert. Northward from the Little Colorado River at Cameron the belt becomes narrower, and extends along the west side of Echo Cliffs to Lee's Ferry. The Chinle formation is exposed in the southern part of Monument Valley and in a wide belt southward from Many Farms to Ganado in Chinle Valley, in another belt southward from Round Rock along the west side of the Chuska Mountains and down Black Creek Valley to a point about 7 miles south of Saint Michaels, and in a belt extending eastward along the north flank of the Zuni Mountains.

The Chinle formation is not satisfactory as an aquifer in most parts of the Navajo Country. Ground water in the Chinle formation generally is too highly mineralized to be suitable for domestic use, although it is usually suitable for livestock. In most places only limited supplies are available because the water-bearing sandstone beds are thin and of limited areal extent. In Black Creek Valley the sandstones of the Chinle formation yield water more readily to wells. In the area north of the Zuni Mountains, along U. S. Highway 66, a prominent sandstone in the middle member contains ground water under sufficient artesian pressure to cause some wells to flow.

Jurassic (?) system

A recent paper by Harshbarger, Repenning and Jackson (1951) describes the occurrence, distribution, and relationships of the Jurassic rocks of the Navajo country. In order to minimize repetition, the discussion of Jurassic rocks in this report will be brief.

Glen Canyon group. - This group is considered to be of Jurassic (?) age. The group includes, in ascending order, the Wingate sandstone, the

Kayenta formation, and the Navajo sandstone. The principal area of outcrop is in the northwestern part of the region an includes Kaibito Plateau and the area from Kayenta to Mexican Water. Smaller areas of outcrops are along the east side of Black Creek Valley and at the base of the cliffs along U. S. Highway 66 east of Gallup.

The Wingate sandstone does not yield water to wells in most parts of the region. No wells are known to yield water from the Kayenta formation. The Navajo sandstone constitutes one of the best aquifers in the Navajo country. On Kaibito Plateau the annual precipitation is small, but drainage is poor and a large part of the moisture that falls evaporates or is absorbed by the rocks. The water that is absorbed percolates downward through the Navajo sandstone to the top of the underlying relatively impermeable Kayenta formation. The Navajo sandstone is water bearing except in those places where local structural deformation has raised the formation above the water table. The formation is relatively free of soluble mineral matter and therefore the ground water it contains is of good quality unless contaminated by soluble matter dissolves from other formations.

Jurassic system

San Rafael group. - This group unconformably overlies the Glen Canyon group and is of definite Jurassic age. The San Rafael group in the Navajo country includes, in ascending order, the Carmel formation, the Entrada sandstone, the Todilto limestone, and the Summerville formation The areal distribution of the San Rafael is less extensive than that of the Glen Canyon. San Rafael strata form a belt along the periphery of Black Mesa, southward from the Four Corners area along the west side of the Chuska Mountains to Lupton, Ariz., and parallel with U. S. Highway 66 east of Gallup.

The rocks of the San Rafael group are not considered good aquifers. The Carmel formation yields limited supplies of water to wells in a few places. The permeability of the Entrada sandstone is generally low and it is not a satisfactory aquifer in most places. The Todilto limestone, a dense, platy, unfractured unit, is not water-bearing. In the Navajo country the Summerville formation consists of intercalated mudstone and poorly sorted sandstone. Due to these poor water-bearing properties the formation does not yield water readily.

Cow Springs sandstone. - According to Harshbarger, Repenning, and Jackson (1951) some of the Upper Jurassic units in the area grade laterally southwestward into a distinct sandstone facies. This sandstone facies is believed to be primarily wind deposited, and from its optimum development near Cow Springs, Ariz., has been named the Cow Springs sandstone by Harshbarger (1951). The Cow Springs sandstone yields water to wells in many parts of the Navajo country. It is believed that, with more knowledge of this unit, ground water can be developed in many localities in sufficien quantities for livestock and domestic use.

Morrison formation. - In the Navajo country the Morrison formation is represented by four members. These are, in ascending order, the Bluff sandstone member, the Recapture shale member, the Westwater Canyon sandstone member, and the Brushy Basin shale member. Both the Recapture and the Brushy Basin members are high in clay content and generally are considered poor aquifers. The Bluff sandstone member contains beds of well

sorted, clean sand alternating with thin poorly sorted siltstone beds. The member yields water to three flowing wells in the area between Toadlena and Shiprock, N. Mex. Similar lithologic relations are present in the Westwater Canyon sandstone member and it is considered a potential aquifer.

Cretaceous system

Dakota sandstone. - The Dakota sandstone is the lowermost of the Cretaceous rocks in the region. This sandstone is composed principally of medium- to coarse-grained sand with a few conglomeratic lenses. In some places the sandstone is divided into two units by an intervening zone of siltstone and claystone with some coal lenses. The Dakota sandstone is widely distributed in the Navajo country. The formation crops out along the margins of Black Mesa and along the west and south sides of the San Juan Basin. The thickness ranges from a few feet to 100 feet in the region.

The Dakota sandstone is considered a good aquifer in the Navajo country. Many wells in the southern part of Black Mesa and along the margins of the San Juan Basin obtain water from the formation.

Mancos shale. - Conformably overlying the Dakota sandstone, the Mancos shale consists of brown to black siltstone and claystone with occassional thin streaks of sandstone and gypsiferous stringers. It is from 500 to more than 1,000 feet thick. The Mancos shale crops out around the margins of Black Mesa and along some of the stream courses within the mesa; along the southern and southwestern sides of the San Juan Basin; and in a large area extending northward from Toadlena to the type locality in southwestern Colorado. The Mancos shale is not water bearing in the Navajo country.

Mesaverde formation. - Lying conformably above the Mancos shale, the Mesaverde formation consists of alternating beds of sandstone, siltstone and claystone. Coal commonly occurs in the shale units. The formation has been divided into many members, but a detailed discussion of them is beyond the scope of this report. In the southeastern part of the Navajo country the following members comprise the Mesaverde formation in ascending order: the Gallup sandstone member, the Dilco coal member, the Dalton sandstone member, the Bartlett barren member, the Gibson coal member, the Hosta sandstone member, and the Allison sandstone member. (Sears, J. D., Hunt, C. B., and Hendricks, T. A., 1941 pp. 101-119). Some of the sandstone members are 250 feet or more thick and extend over several hundred square miles. The aggregate thickness of these members in the Gallup-Zuni area is of the order of 2,000 feet. The Mesaverde formation crops out over most of Black Mesa and that part of the San Juan Basin which lies in the Navajo country.

The sandstones of the Mesaverde formation constitute one of the best aquifers of the region. Throughout the San Juan Basin dozens of artesian wells produce water from these sandstones. Few wells have been drilled in the northern part of Black Mesa, but in the southern part the Mesaverde formation yields water to several wells.

Igneous rocks

Tertiary system

Tertiary rocks lie unconformably upon Cretaceous and older rocks in some parts of the Navajo country. One zone about 20 to 30 miles wide extends southeastward from near Jeddito to the vicinity of Wide Ruins. In this area the unnamed deposits consist of up to 300 feet of poorly consolidated, poorly sorted sandstone with intercalated layers of siltstone, claystone, and volcanic flows and tuffs. The Chuska Mountains are another area of Tertiary deposits. In this vicinity the Tohachi shale, about 200 to 300 feet thick, is overlain by about 700 feet of Chuska sandstone. At the eastern side of the Navajo country, in the center of the San Juan Basin, as much as several thousand feet of Tertiary materials have been deposited.

The water-bearing properties of the Tertiary deposits are variable, and the rocks are not considered good aquifers in the region. In the Jeddito-Wide Ruins area the rocks in some places have satisfactory properties as an aquifer, but commonly they lie in mesas, so that water which may have percolated into them seeps out again around the base. Percipitation on the Chuska Mountains is higher than average; no wells have been drilled because springs and small water holes yield sufficient water for livestock and domestic use. The Tertiary rocks in the central part of the San Juan Basin lie mostly outside the boundary of the Navajo Indian Reservation. Within the Reservation these rocks supply water for several shallow dug wells.

Quaternary system

Alluvial deposits, consisting mostly of fine-grained unconsolidated sand with some gravel, silt, and clay, underlie most of the streams and drainage channels in the region. The thickness of these deposits ranges from a few inches to a maximum of about 200 feet, but in most places the thickness is less than 50 feet.

The Quaternary alluvium is water bearing in those places where recharge is available from springs or flood runoff. Where there is 10 feet or more of alluvium below the water table there is usually sufficient water available to supply a dug well or an infiltration gallery. However, the storage capacity of the alluvium is small, and the water table fluctuates rapidly in response to changes in the relation between recharge and discharge. Furthermore, down-cutting of the streams has lowered the water table in many places and reduced the storage capacity of the alluvium.

IGNEOUS ROCKS

Igneous rocks in the Navajo country occur as dikes, necks, and lava flows. The region is dotted with these igneous rocks, particularly in the Hopi Buttes volcanic field south of the Hopi Indian Villages. The igneous rocks of the region are not known to be water bearing except in Buell Park, where springs issue from agglomeratic breccia. Three springs in this area yield 150 to 250 gallons per minute.

MAJOR STRUCTURAL FEATURES AND THEIR RELATION TO WATER SUPPLIES

The major structural features of the Navajo country are the Black Mesa Basin, the southwestern part of the San Juan Basin and the intervening Defiance Uplift (see pl. 1). The Black Mesa Basin is in the Arizona part of the Navajo country. The eastward-dipping beds of the Kaibab and Echo Cliffs monoclines form the western side of the basin. The Black Mesa Basin is bounded on the north by the Comb Ridge monocline. The west flank of the Defiance Uplift is the eastern margin of the basin. The eastern monoclinal limb of this broad anticlinal structure forms the western edge of the San Juan Basin. Two and one-half miles east of Gallup, N. Mex., the steep westerly dipping Nutria monocline forms the northwest flank of the Zuni Uplift which delimits the southwestern part of the San Juan Basin. Two prominent laccolithic mountains occur in the northern part of the Navajo country. These are the Carrizo Mountains, which lie north of the Defiance Uplift, the Navajo Mountain which lies in the northwestern part of the region (see pl. 1). The regional attitude of the beds is modified by many local monoclines, anticline, and synclines. Each of these has its effect on the occurrence of ground water. Generally, ground water is more readily available in the syncline than on an anticline. Due to structural highs, aquifers are exposed to recharge from rainfall, snowmelt, and runoff.

Faulting is not very extensive in the Navajo country. There are several notable strike faults along the monoclinal limbs of the Defiance Uplift and small tension faults occur at several localities along the elongated dome. In the southwestern part of the region faults of small displacement have been found in the Kaibab limestone. In this area the faults and joints are believed to facilitate recharge to the underlying Coconino sandstone. Some faulting has occurred in the Mesaverde and older rocks in the extreme eastern part of the region, south of Crownpoint.

The structural features of the region are of major importance in the occurrence of ground water. The Black Mesa basin and the San Juan Basin are large saucer-shaped depressions. The successive rock layers are exposed at the land surface on the perimeter of the basin, and dip beneath the surface toward the center. Water enters the permeable formations where they are exposed at the land surface, and moves down dip toward the center of the basin. The water moves slowly and dissolves some of the soluble mineral matter contained in the rocks through which it passes, becoming progressively more highly mineralized. The ground water is discharged from the formation by springs in canyons or along mesa escarpments, by pumped and flowing wells, or by upward seepage into overlying beds.

In selecting a site for a water well the structural relations should be considered. Wells drilled near the outcrop will penetrate the formation above the zone of saturation. Farther down dip, a greater well depth will be required, but the formation will be saturated and the well will be successful. Toward the center of the basin, many miles from the outcrop zone, water would be encountered at great depths and may be too highly mineralized for domestic or livestock use. Local structural conditions alter these generalized relations. Faults impede or divert the movement of ground water and thus affect the liklihood of obtaining water from wells in some localities.

PRINCIPAL AQUIFERS OF THE REGION

In general, the aquifers of the Navajo country are less permeable than the principal aquifers in other parts of Arizona and New Mexico. The reader should bear in mind that the terms "good aquifer" and "poor aquifer" are relative. For example, in the Navajo country a well that yields as much as 100 gallons per minute is rare, but in parts of southern Arizona and New Mexico a well that yields less than 500 gallons per minute is considered a failure. The permeability of the aquifers in the Navajo country, based on pumping tests, ranges from 1 to 40 gallons per day per foot. The permeability of the gravels of the Gila River, near Safford, Ariz., commonly is 500 to 2,000 gallons per day per foot.

The Permian sandstones of the region constitute one of the principal aquifers. Recharge occurs directly on the outcrops and through the overlying limestone where it is faulted or deeply fractured. In the southwest part of the Navajo country several windmill-powered wells pump water from the Coconino sandstone at a rate of 3 to 5 gallons per minute. These wells are believed capable of producing greater discharges with larger pumping equipment. Two wells recently drilled to a depth of about 2,450 feet near Klagetoh each yield 35 gallons per minute from the Coconino sandstone. A well at Ganado is reported to be capable of yielding 100 gallons per minute from the Coconino sandstone. Nutria Springs, which issue from the Glorieta sandstone member of the San Andres formation on the southwest flank of the Zuni Mountains, discharge more than 200 gallons per minute. Other notable springs are in the Fort Defiance area and near Toadlena. Areas of potential future development of the Permian sandstones for livestock and domestic water supplies include Chinle Valley south of Chinle, Black Creek Valley from Red Lake south to Oak Spring, and further development in those areas where wells have already been drilled. The required depth of wells will range from 800 to 2,000 feet.

The Sinarump conglomerate is water bearing in a large part of the region. The greatest yield is obtained from wells in Black Creek Valley; at St. Michael's School a yield of 50 gallons per minute was obtained with a drawdown of 36 feet. It is believed that many more wells for livestock and domestic use could be successfully developed along the north end of the Defiance uplift, in Black Creek Valley, along the north flanks of the Zuni Mountains, possibly in parts of Chinle Valley, and possibly in the southern and southwestern part of the Navajo country.

The Navajo sandstone, in the western and northwestern part of the Navajo country, is considered one of the best aquifers. A well recently drilled to a depth of 1,240 feet at Kaibito Day School yielded 10 gallons per minute with a drawdown of 1 foot during a bailing test. A well drilled 840 feet deep at Kayenta in 1948 yielded 100 gallons per minute with a drawdown of 184 feet during a pumping test. Three springs at Tuba City yield a total of more than 125 gallons per minute. In a canyon a few miles east of Tuba City a group of springs yield about 200 gallons per minute. Other springs, west of Tuba City, yield over 200 gallons per minute. Many more wells could be drilled into the Navajo sandstone for livestock and domestic use without overdeveloping the formation. The required depth ranges from 300 to 1,500 feet.

The Jurassic Cow Springs sandstone described by Harshbarger, Repenning, and Jackson (1951, p. 2) is potentially a good aquifer. The formation is widespread and apparently has uniformly good water-bearing properties. The formation is believed capable of additional development in some areas.

The Dakota sandstone is water bearing in most places and is considered a good aquifer in the region. The ground water is of suitable quality for domestic use in most places, although in those localities where shale and coal predominate the water is more highly mineralized. Further development for livestock use is justified in most of the areas where the formation is within economic reach of the drill.

Considering the areal distribution and the quantity of water available to wells, the Mesaverde formation of the San Juan Basin contains the best aquifers in the region. Many of the wells in the basin flow; a well 873 feet deep, drilled a few miles east of Twin Lakes, flows 90 gallons per minute and has a static shut-in pressure that would lift water over 250 feet above the land surface. The Gallup sandstone member, the Dalton sandstone member, and the Hosta sandstone member are the principal water-bearing members of the Mesaverde formation and all are believed capable of further development. Water from the Mesaverde formation is of satisfactory quality for domestic use in some places, but in other places the water contains excessive amounts of sodium, sulfate, and bicarbonate. In some places fluoride concentrations are excessive. In the Black Mesa Basin a few wells have been drilled into the Mesaverde formation but three wells drilled during the first half of 1951 indicate that small supplies are available in those areas where structural and recharge conditions are favorable. Here, also, the water is soft but is highly mineralized in some localities.

The Quaternary alluvium is not considered a dependable aquifer throughout the Navajo country because the amount of water it contains fluctuates quickly in response to changes in recharge. Many shallow wells fail in drought years. Water from the alluvium has a wide range of dissolved solids concentration and may be of good, fair, or poor quality, depending upon local conditions. Nevertheless, the alluvium constitutes an aquifer that can be tapped relatively cheaply and, if it is realized that wells are likely to fail at times, can be used to furnish livestock and domestic water supplies. The alluvium is not adequate to supply water for irrigation, schools, communities, or hospitals, except in those places where recharge occurs from perennial streams or from springs whose source is underlying beds. At the mouth of Canyon DeChelly the alluvium is over 200 feet thick and is recharged from surface runoff and effluent water from the Permian sandstones along the Defiance uplift. A well drilled into the alluvium to supply the community of Chinle yielded 500 gallons per minute with a drawdown of 65 feet.

SUMMARY

Although ground water is widely distributed in the Navajo country, the quantity available at any locality is small. The arid climate and the rough terrain of canyons, mesas, cliffs, and buttes combine to reduce the amount of recharge available to the aquifers. The aquifers have low permeability and do not transmit water readily. Lithologic changes in some of the formations affect the availability of ground water to wells in some localities. Locally, structural uplifts have raised some formations above the water table and have diverted the slowly moving ground water in other localities. However, in most parts of the Navajo country sufficient ground water for livestock and domestic use can be developed, although in some areas wells as deep as 1,500 to 2,000 feet are required to obtain sufficient water. There is little hope of developing ground water in sufficient quantity for irrigation, except from alluvium in places where recharge is abundant.

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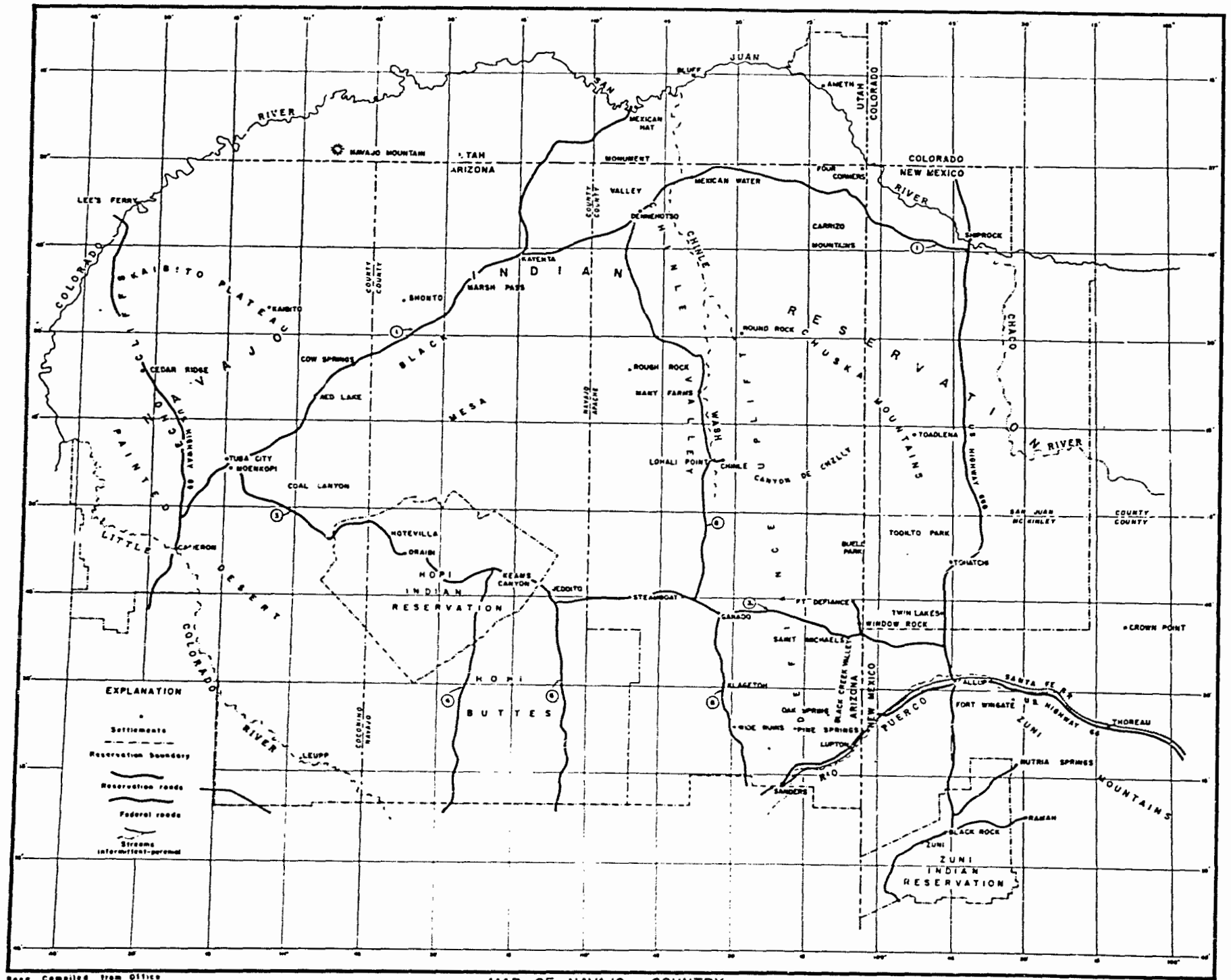

Base Compiled from Office of Indian Affairs Map 1937

MAP OF NAVAJO COUNTRY
ARIZONA, NEW MEXICO, UTAH, and COLORADO

Scale in miles

CV-6417-201

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