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Water-Supply Investigation of Keams Canyon Area, Hopi Indian Reservation, Navajo County, Arizona

By

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With a section on

Quality of Water

By

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ABSTRACT

The ground-water resources of the Keams Canyon area were investigated by the Ground Water Branch of the United States Geological Survey in the fall of 1949 and the spring of 1950. The area lies between latitudes 35°30', and 36°00', and between longitudes 110°00' and 110°15', in the Hopi Indian Reservation, Navajo County, Ariz.

The geologic section exposed in the area includes Cretaceous, Tertiary, and Quaternary rocks. The water-bearing character of these rocks is discussed, and the report includes a discussion of the underlying Permian, Triassic, and Jurassic rocks as possible sources of additional water for the Keams Canyon community. In the Cretaceous and older rocks the structure consists of gentle flexures dipping generally southeast. The Tertiary rocks are essentially flat-lying. Quaternary rocks are restricted to alluvial fill in canyons and valleys.

The existing water supply for the Keams Canyon community is obtained from two wells in the alluvial fill of the canyon and from three springs within the canyon. The total supply, as measured in January 1950, is about 50 gallons per minute, 42 gallons per minute from the wells and 8 from the springs. The Office of Indian Affairs desires an increase in the water supply to a total of 105 gallons per minute, due to proposed enlargement of the community.

Four possible methods of increasing the water supply were considered: (1) Construction of a pipe line to other springs in the canyon; (2) construction of an additional well in the alluvium; (3) construction of a ground-water dam across the fill; and (4) drilling a deep well. The construction of a pipe line to additional springs was not considered feasible owing to the fact that maintenance would be expensive. Construction of an additional well in the alluvium was abandoned after an electrical resistivity survey indicated insufficient alluvium to warrant drilling a well at the only practicable site. A ground-water dam in the fill, downstream from the existing wells to maintain a higher level of the water table, is recommended. An alternate source of additional water may be the Permian Coconino sandstone. The water-bearing character of this formation can be determined by drilling and test pumping a well. The required depth of the well would be 3,500 to 3,800 feet.

INTRODUCTION

At the request of the Office of Indian Affairs, the Ground Water Branch of the Geological Survey is making a regional reconnaissance of the ground-water resources of the Hopi Indian Reservation, Ariz., and the Navajo Indian Reservation, which lies in Arizona, New Mexico, and Utah. In addition, detailed studies are being made in areas where specific problems require immediate attention. An investigation of the Keams Canyon area was requested because the water supply for the headquarters of the Hopi Agency, at Keams Canyon, was considered inadequate.

LOCATION OF AREA

The area described in this report lies between latitudes 35°30' and 36°00', and between longitudes 110°00' and 110°15', in the southeastern part of the Hopi Indian Reservation (see fig. 1), Navajo County, Ariz. The community of Keams Canyon, in the west-central part of the area, is about 75 miles north of the nearest railroad station, at Holbrook, Ariz. This community, which is situated on the floor of a deep, narrow canyon of the same name, includes the agency headquarters, a school, a hospital, two churches, two trading posts, and associated dwellings. The population in January 1950 was reported to be about 700.

TOPOGRAPHY AND DRAINAGE

The Keams Canyon area lies within the Colorado Plateau topographic province. The northern half of the area is a part of Black Mesa, a high plateau that is one of the principal topographic features of the region. The southern half consists of broad flat valleys marked by numerous lava-capped buttes and volcanic necks, a part of the Hopi Buttes geographic

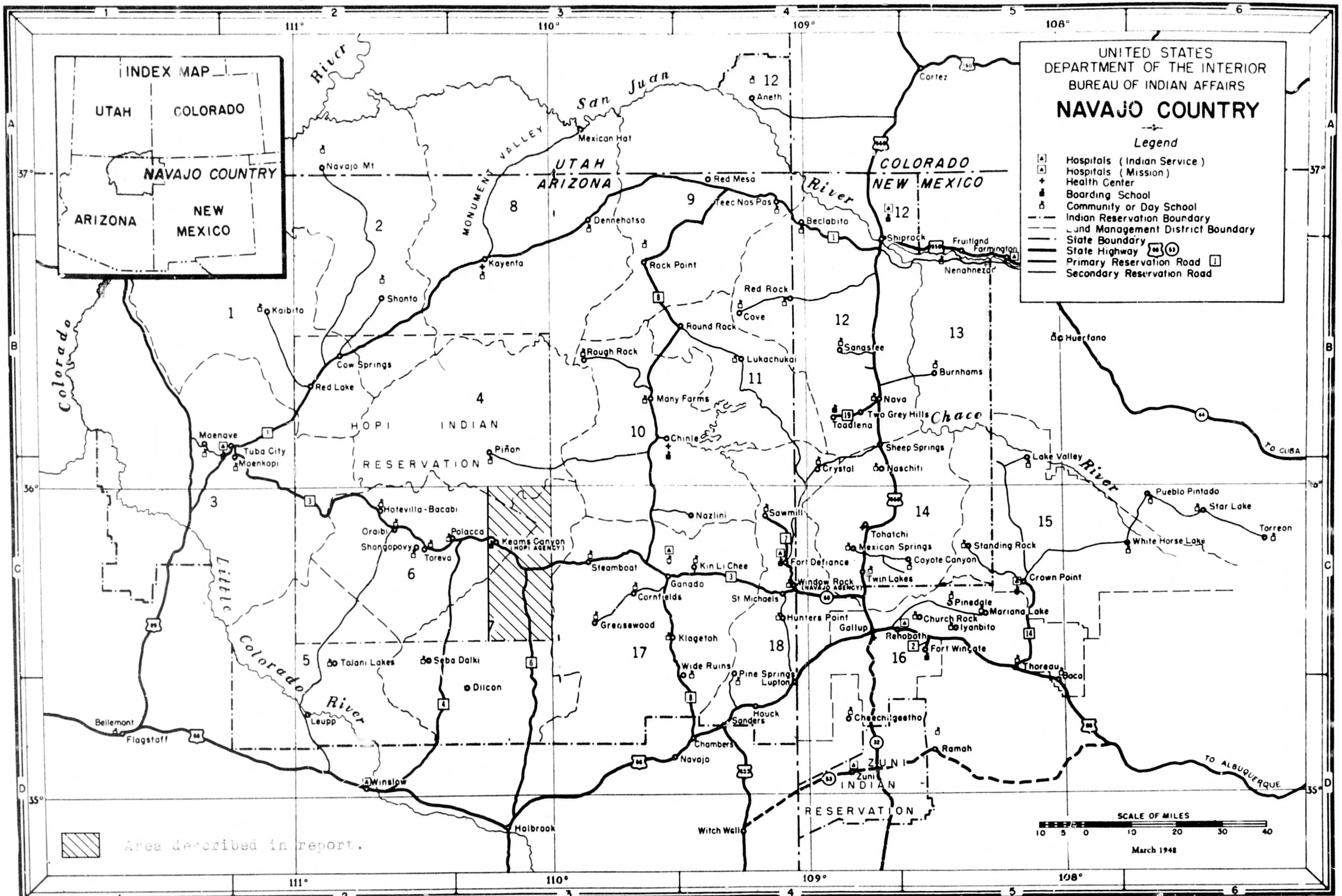

Figure 1.—Map of Navajo Country, showing area described in report.

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subprovince.[1]

[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, pp. 37-38, 1916.

Altitudes in the Keams Canyon area range from about 5,800 feet in the southwestern part to about 7,200 feet in the northeastern part. The altitude at Keams Canyon is 6,180 feet.

Drainage in the area is toward the southwest. The principal streams are Burnt Corn Wash and Jeddito Wash, which are a part of the Little Colorado River drainage system. These streams head on the southern flank of Black Mesa, where they have cut canyons several hundred feet deep. In the southern part of the area the washes lie in broad valleys.

Surface runoff in the washes occurs only during periods of rainfall or melting snow. In a few places perennial flow occurs in response to discharge from springs, although the flow usually disappears within a short distance downstream owing to losses by transpiration, evaporation, and downward percolation.

The deep, narrow Keams Canyon contains a stream that is tributary to Burnt Corn Wash. At the community of Keams Canyon this stream flows for about 10 months each year as a result of discharge from several springs upstream (see pl. 1).

SUMMARY OF PROBLEM

The existing water supply at Keams Canyon consists of two shallow wells drilled in the alluvium of the canyon floor and springs issuing from the canyon wall upstream. This supply is reported to be barely adequate for the existing community during most of the year, and insufficient in the dry part of the summer.

The estimated maximum demand for water at Keams Canyon is about 105,000 gallons per day, assuming that each of the 700 persons uses an average of 150 gallons per day. It is proposed that the community be enlarged to a total population of 1,000, which would require about 150,000 gallons per day, or about 105 gallons per minute.

On the basis of data collected during the investigation, the daily consumption of water at Keams Canyon in 1949-50 ranged from 29,000 gallons in the winter to 46,000 gallons in the summer, equivalent to per-capita daily rates of 41 gallons and 66 gallons, respectively. These per-capita rates of consumption are considerably below those noted at some other communities in the region. For example, at Chinle, Ariz., the daily rate of consumption per capita was 250 gallons in the winter of 1947-48, and at Fort Defiance the rate was over 300 gallons in the summer of 1949. On the basis of existing rates of water consumption at Keams Canyon, a maximum supply of 66,000 gallons per day would be sufficient to meet the demands of the community after expansion to a population of 1,000. However, it is expected that if a more adequate supply of water were developed the per-capita rate of consumption would rise, and officials of the Office of Indian Affairs consider it desirable to develop a supply of at least 150,000 gallons per day.

In recent years a heavy growth of phreatophytes has developed along the wash at Keams Canyon, and these plants have reduced the supply of water available to the wells. In addition, downcutting of the stream through the alluvium has lowered the water table since the community was first established.

Four possible methods of developing additional water were apparent at the start of the investigation: (1) Collect the flow from all the springs upstream from Keams Canyon; (2) construct an additional well in the alluvium; (3) construct a ground-water dam in the alluvium a few feet downstream from the existing wells, and thus impound part of the underflow through the alluvium; (4) clean out and deepen an existing test hole to determine whether or not adequate supplies of satisfactory quality could be developed from underlying beds.

FIELD WORK

The geology of the southeast quarter of the Hopi Indian Reservation was studied during the investigation of the Keams Canyon area, partly to determine if additional ground water could be developed at Keams Canyon and partly as a basis for selecting sites for wells that may be drilled in the future. The geologic field work was done by C. A. Repenning, geologist. A geologic map of two 15-minute quadrangles was prepared for this report (pl. 1), and a geologic map of two adjacent quadrangles to the west will be a part of a forthcoming report on the Polacca area. Aerial photographs made for the Soil Conservation Service in 1935 were used for field mapping and locating wells and springs. Field data were transferred to controlled mosaics for the base map. The map (pl. 1) was prepared by adjusting the base map to a Lambert conformal projection, and is a portion of a larger map of the Navajo-Hopi country that is in preparation.

All the wells and important springs in the northern of the two quadrangles shown on plate 1 were visited by H. A. Wahe, engineer, who collected water samples for analysis. In the southern quadrangle, collection of well data was interrupted by a request for immediate preparation of the report. All the wells and springs shown on the map are accurately located, however, and analyses of water samples will be included in a final report on the region.

Production tests were made on the wells and springs that supply Keams Canyon. From data collected during a pumping test on one of the wells, the underflow of the wash at Keams Canyon was computed. This work was done by L. C. Halpenny, assisted by Mr. Hepenning. Geophysical probes to determine the depth of alluvial fill were made by H. H. Shibitske, mathematician.

The work was financed by and was in cooperation with the Hopi Agency, Office of Indian Affairs. The investigations in the Arizona portion of the Navajo Country are coordinated with a systematic investigation of the ground-water resources of Arizona, under the direction of S. F. Turner. This statewide investigation is carried on in cooperation with the Arizona State Land Department.

GEOLOGY AND GROUND-WATER RESOURCES

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

The geologic formations discussed in this report range in age from Permian to Quaternary. Only Upper Cretaceous and younger strata are exposed in the Keams Canyon area. Descriptions of older rocks were obtained from examination of outcrops in adjacent areas supplemented by examination of well logs and drill cuttings and by a review of published data on the geology of the region. The geologic section is as follows:

QUATERNARY	
Recent	Alluvium
TERTIARY (?)	Calcareous spring deposits
TERTIARY	
Pliocene	Bidahochi formation
	Upper member
	Middle volcanic member
	Lower member
CRETACEOUS	
Upper Cretaceous	Mesaverde formation
	Upper member
	Lower member
	Mancos shale
	Dakota sandstone
JURASSIC	
Upper Jurassic	Morrison formation
Upper and Middle Jurassic	San Rafael group
	Carmel formation
JURASSIC (?)	Glen Canyon group
	Wingate sandstone
TRIASSIC	
Upper Triassic	Chinle formation
	Shinarump conglomerate
Lower Triassic	Moenkopi formation
PERMIAN	Coconino sandstone

Permian System

Coconino sandstone.--The Coconino sandstone is at least 620 feet thick in the vicinity of Holbrook, Ariz.[2] Farther south, along the

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[2] Darton, N. H., A résumé of Arizona geology: Arizona Bur. Mines Bull. 119, p. 92, 1925.

Mogollon Rim, thicknesses of 1,000 and 1,100 feet have been measured. The sandstone thins to the north and east and is replaced partly by the DeChelly sandstone at Canyon DeChelly, about 50 miles northeast of Keams Canyon. The DeChelly sandstone at Canyon DeChelly is approximately 800 feet thick. The relation between the Coconino and the DeChelly at Keams Canyon is not known, but it is believed that at least 400 feet and possibly as much as 700 feet of these sandstones are present at depth. The Coconino is a white to orange-red fine-grained quartz sandstone. Where observed by Repenning, the Coconino sandstone is characteristically cross-bedded on a large scale. West and southwest of Keams Canyon the Coconino sandstone is overlain by the Kaibab limestone, but it is believed that this formation is not present in the Keams Canyon area. Hence, the Coconino sandstone probably is overlain unconformably by the Lower Triassic Moenkopi formation.

The Coconino sandstone is recharged along the Defiance uplift 55 miles east of Keams Canyon and along the Mogollon Rim south and southwest of Holbrook. The formation yields water under artesian pressure to wells in the vicinity of Holbrook. It is believed that the sandstone is water bearing in the Keams Canyon area, but no wells penetrate the formation. Before reliable predictions can be made regarding the quantity and quality of water available from the Coconino sandstone at Keams Canyon, a test hole will be required.

Triassic System

Lower Triassic Series

Moenkopi formation.--The Moenkopi formation crops out at Holbrook.

where Gregory[3] measured a section 124 feet thick. The formation thick-

[3] 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, pp. 26-27, 1917.

ens northwest of Holbrook toward the type locality, 100 miles west of Keams Canyon, and thins from there toward the northeast. At the east end of Oljeta Mesa, in the Monument Valley region, the Moenkopi formation is 80 feet thick.[4] It is absent on the Defiance uplift, 45 miles east of

[4] Baker, A. A., Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U. S. Geol. Survey Bull. 865, p. 43, 1936.

Keams Canyon, but is believed to be 150 to 250 feet thick in the Keams Canyon area. The Moenkopi formation consists of interbedded red to chocolate-brown sandstones and shales. The sandstones locally are cross-bedded on a small scale. Mud cracks, rain pits, ripple marks, and frequent veins of gypsum are characteristic of the formation. A few zones contain nodules of limestone.

The Moenkopi formation is not water bearing in most places, but at a few localities small supplies have been encountered in the sandstone beds. Owing to the high content of evaporites, however, the water is highly mineralized.

Upper Triassic Series

Shinarump conglomerate.--The Shinarump conglomerate is exposed for many miles along the Little Colorado River southwest of the Keams Canyon area. The formation is persistent throughout most of the Navajo-Hopi region, and ranges in thickness from approximately 50 feet at Holbrook to 140 feet in the Monument Valley region. In the Keams Canyon area the thickness of the Shinarump conglomerate is estimated to be at least 50 feet. Where exposed at Holbrook the conglomerate consists of white to gray quartz sandstone and interbedded conglomerate lenses. The sandstone is typically coarse-grained and has isolated pebbles scattered throughout. The conglomerates comprise rounded fragments of quartzite, chert, and petrified wood, ranging in size from pebbles to cobbles. Cross-bedding on a small scale is common. Petrified logs occur in the upper part of the formation and fragments are scattered throughout. Locally, the contact between the Shinarump conglomerate and the overlying Chinle formation was observed to be unconformable, and in some places erosion has removed the conglomerate so that the Chinle lies upon older rocks.

In most parts of the region the Shinarump conglomerate is a good aquifer, which yields small quantities of water suitable in quality for domestic use. In the Keams Canyon area, geologic evidence indicates that water in the Shinarump conglomerate should be under artesian pressure.

Chinle formation.--The Chinle formation is about 1,000 feet thick 40 miles south of Keams Canyon. At the type locality, about 40 miles east of Keams Canyon, the formation is 950 feet thick. To the north, in Monument Valley, it is 825 to 925 feet thick. Accordingly at Keams Canyon it is estimated to be between 900 and 1,000 feet thick. The formation consists of three main units, a lower unit of shale and interbedded sandstone, a middle shale unit, and an upper unit of shale and interbedded limestone. The lower unit consists of red and gray sandy shales with interbedded red-brown to dark-brown, medium-to fine-grained, lenticular sandstones. Cross-bedding on a small scale is common in the sandstones. The middle unit consists of variegated shales and marls ranging in color from light gray and purple gray to dark reddish brown. Petrified logs are abundant in this unit. The upper unit consists of beds of dark-red sandy shale, from 3 to 20 feet thick, alternating with lenses of gray cherty limestone from 1 to 10 feet thick. In places the shales grade laterally into silty sandstone.

The Chinle formation is not a good aquifer, although in some localities small supplies of water have been developed in the sandstone beds. For the most part, however, water in the Chinle formation is of poor quality and is suitable only for livestock. Therefore, this formation is not considered to be a possible source of water for Keams Canyon.

Jurassic (?) System

Glen Canyon group.--The Wingate sandstone, basal formation of the Glen Canyon group, crops out 40 miles south of Keams Canyon in a prominent cliff face. The total thickness of the Wingate sandstone here is 950 feet. About 35 miles east of Keams Canyon, on the west side of the Defiance uplift, the formation is 625 feet thick. In Monument Valley it is 500 feet thick. It is estimated that at Keams Canyon the formation is 700 to 800 feet thick. The Wingate sandstone is massive, dark red, fine grained, and cross-laminated on a large scale. In some exposures the formation contains limestone lenses, some of them as much as half a mile across.

In addition to the Wingate sandstone, the Glen Canyon group includes, in ascending order, the Kayenta formation and the Navajo sandstone. These formations probably are not present at Keams Canyon, as they are not recognized south and east of the area.

The Wingate sandstone is too fine grained and silty to be a potential source of adequate supplies of water to a well at Keams Canyon, although small supplies might be developed for domestic and livestock use.

Jurassic System

Middle and Upper Jurassic Series

San Rafael group.--The Carmel formation, basal unit of the San Rafael group, is 215 feet thick where exposed 35 miles south of Keams Canyon. A comparable thickness is believed to underlie the Keams Canyon area. In the outcrop area the formation consists of red silty sandstone and dark-red shale. The San Rafael group in the Navajo country includes, in ascending order, the Carmel formation, the Entrada sandstone, and the Todilto limestone member of the Wanakah formation. Reconnaissance investigations of the geology of the region indicate that these formations are not likely to be present in the Keams Canyon area.

The Carmel formation is not considered an aquifer in most parts of the region, and is not expected to yield sufficient water at Keams Canyon to supply a well.

Morrison formation.--The Morrison formation is 200 feet thick where exposed a few miles southwest of the mapped area. In this locality the formation consists of sandstones with interbedded sandy shales, and it is highly gypsiferous. The sandstones are pale green to pale reddish brown, fine-grained, silty, and cross-laminated on a large scale. Two zones contain cherty gray limestone lenses, ranging in thickness from a few inches to 3 feet. The upper limestone contains large bipedal dinosaur tracks. The formation is overlain unconformably by the Dakota sandstone.

The Morrison formation yields water to wells west and southwest of the Keams Canyon area, but the associated gypsum in the sandstones is reported to make the water undesirable for domestic use. In other parts of the region the Morrison formation yields small supplies of water that is suitable for domestic use. It is impossible to determine the quality of water in the Morrison formation at Keams Canyon without drilling a test well.

Cretaceous System

Upper Cretaceous Series

Dakota sandstone.--The Dakota sandstone, with local variations in lithology and a wide range in thickness, is persistent over most of the Navajo-Hopi region. Characteristically, the formation is exposed as resistant caps on mesas and cuesta dip slopes. The thickness of the Dakota sandstone in the Keams Canyon area is 25 feet, and exposures are typical of those elsewhere in the region. Where exposed in the southwestern part of the area the formation is principally white to gray, coarse-grained sandstone divided into two parts by a unit of carbonaceous shale. In places the upper and lower sandstones are replaced by the shale unit. Specimens of Exogyra costata Say (?) are locally abundant in the upper sandstone zone, and deciduous leaves are common in the middle shale zone. Small deposits of coal occur in the shale zone near the Keams Canyon area.

The Dakota sandstone yields water to wells in many parts of the Navajo-Hopi region, and in some places the water is under artesian pressure. A test hole was drilled to a depth of 1,288 feet at Keams Canyon about 1915, and water from the Dakota sandstone is reported to have risen to within 200 feet of the land surface.[5] A log of this well

[5] 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, p. 175, 1917.

(K-85) is given in table 2, but no data are available regarding the quantity or quality of water produced. The well was still in existence in 1950, and it is suggested that it be cleaned out and tested.

Mancos shale.--The Mancos shale is 1,070 feet thick at Keams Canyon, based on the log of well K-85 and on field observations. It is a dark-gray to black fissile shale, carbonaceous in part. In the upper part a few thin light-brown silty sandstones contain an abundance of Prionotropis woolgari Mantell, of Benton age.

The Mancos shale is not an aquifer.

Mesaverde formation.--An almost continuous outcrop of Mesaverde strata occupies most of the northern half of the Keams Canyon area. Exposures range in thickness from about 300 feet at Keams Canyon to more than 1,200 feet in the northern part of the area. The formation is divided into two members. The lower member is about 600 feet thick and consists of 150 feet of cliff-forming sandstone overlain by a series of alternating sandstones and sandy shales. The basal unit of the lower member is a white to tan, medium-to coarse-grained, poorly sorted sandstone that is cross-laminated on a small scale. Coal is mined at several localities from deposits near the base of the sandstone. An ironstone layer, 10 to 20 feet higher in the section, locally contains abundant deciduous leaf impressions. The upper 450 feet of the lower member consists of gray lenticular sandstones interbedded with gray sandy shales.

The upper member of the Mesaverde formation is exposed in the northwest corner of the mapped area. The lithology of this member is like that of the lower member, with 270 feet of cliff-forming tan sandstones overlain by more than 330 feet of shales interbedded with thin sandstones. Erosion has stripped off Mesaverde strata in increasing amounts toward the southeast with the result that, in the east-central part of the area, Tertiary beds rest directly upon the Mancos shale.

The lower member of the Mesaverde formation yields water to wells in the northern part of the Keams Canyon area. The amount of water available depends upon the thickness and areal extent of the aquifers penetrated. The springs upstream from Keams Canyon issue from the lower member of the formation. The Mesaverde formation would not be encountered in a well drilled at Keams Canyon, as the log of well K-85 (table 2) indicates that the alluvial fill is immediately underlain by the Mancos shale.

Tertiary System

Pliocene Series

Bidahochi formation.--The Bidahochi formation, of Pliocene age[6],

6/ Hack, J. T., Sedimentation and volcanism in the Hopi Buttes, Ariz.: Geol. Soc. America Bull., vol. 53, no. 2, pp. 335-372, 1942.

occupies most of the southern half of the Keams Canyon area. The formation is 300 to 450 feet thick and is separable into three major divisions: A lower member of shales and tuffs, a middle volcanic member, and an upper sandstone and shale member. The lower member consists of 100 feet of gray, white, and reddish shales and interbedded tuffs. The volcanic member, which is an augite-rich basalt and basaltic agglomerate, ranges in thickness from a few inches to 150 feet. In some places the volcanic member is not present. The upper member is composed of 200 feet of white to dark-gray sandstones and interbedded shales which are similar to those in the lower member. The shales predominate toward the bottom of the member. The sandstones are made up of quartz grains and coarse particles derived from the lavas of the volcanic member. They are massive, poorly cemented, and cross-laminated on a small scale.

An outcrop of the volcanic member that appears in the midst of upper Bidahochi deposits east of Reservation Highway 6 is interpreted as a remnant of a volcanic vent formed prior to deposition of the upper member.

The Bidahochi formation is not a particularly good aquifer in the area. The formation is flat lying and the sandstone unit of the upper member is moderately permeable, so that rainfall is readily absorbed. However, the upper member usually caps the mesas, and water entering the formation is discharged by seepage.

Tertiary (?) System

In the southern part of the area calcareous spring deposits occur in conjunction with ring-shaped outcrops of agglomerate that Hack[1] refers

[1] Op. cit., 1942.

to as diatremes. These deposits are believed to be younger than the upper sandstone and shale member of the Bidahochi formation.

The spring deposits cannot be considered as a source of water in the Keams Canyon area.

Quaternary System

Alluvium.--The washes in the Keams Canyon area are underlain by unconsolidated alluvium of Recent age. The thickness of the alluvium ranges from a few inches to about 100 feet. In addition, thin layers of wind-blown sand cover the older rocks in places. Alluvium is shown on the map (pl. 1) in those places where local water supplies might be developed. The scale of the map would not permit showing the alluvium in a few localities, although it is an important source of ground water.

About 100 feet of alluvial fill underlies the wash at Keams Canyon. Figure 2 is a cross section prepared by engineers of the Office of Indian Affairs on the basis of a series of test holes drilled across the canyon. The upper 30 feet of alluvial fill has been exposed by downcutting in the wash channel, and the materials in this zone are silty sand. Drill cuttings show the material near the bottom of the fill to be coarser and to contain some gravel.

The alluvium underlying the washes is water bearing in most places although usually only small supplies are available because the material is fine grained. At Keams Canyon the alluvium yields a maximum of about 25 gallons per minute to each of two wells. Recharge is derived principally from springs upstream that issue from the lower member of the Mesaverde formation.

STRUCTURE

The dip of the Mesaverde strata in the northern part of the Keams Canyon area is 2° to 3° SE. Southward, the overlying Bidahochi strata dip slightly east. North and west of the area are a few gentle folds which increase in magnitude toward the north. West of the southwest corner of the area is a small dome. No faulting was observed in the area.

WATER SUPPLIES

Table 1 includes records of all wells and springs that were visited during the investigation. Table 2 contains the available well logs, and table 3 lists analyses of the water samples collected. The well numbers beginning with a figure and letters, such as 4K-175, were assigned by engineers of the Office of Indian Affairs. Those beginning with the letter K, such as K-2, are temporary numbers. Springs were assigned temporary numbers ending with an S, such as K-1S.

KEAMS CANYON COMMUNITY

Water for Keams Canyon is obtained from two wells constructed in the alluvium, and from three springs about a mile upstream (inset, pl. 1). These wells and springs supply all but one of the churches and one of the trading posts, which collect water from other springs (see p. 21).

Wells

Wells 6K-303 and K-2 (pl. 1) are the principal source of water for the community. The wells are 156 feet apart on a line parallel with the course of the wash. Records of the wells are given in table 1, and an analysis of the water from well K-2 is given in table 3. In January 1950 the two wells were yielding a total of 42 gallons per minute and were being pumped simultaneously about 7 hours per day. It is reported that during the summer months the wells are pumped 14 hours per day. A third well (K-3, pl. 1) was constructed about 1943, 275 feet upstream from well K-2. This well produced little water and is no longer in use.

A pumping test was made on well K-2, beginning at 2:35 p. m. January 10, 1950, and continuing until 7:23 a. m. January 11. During the test observations of water-level fluctuations were made in wells 6K-303 and K-3 to determine the extent of the cone of depression surrounding the pumped well. Water in the nearby wash was frozen and measurements of stream discharge could not be made.

On the basis of an average discharge of 25 gallons per minute for 17 hours and a total drawdown of 21 feet, the specific capacity of the well was computed to be 1.2 gallons per minute per foot of drawdown. Using the Theis[8] recovery method, the transmissibility of the aquifer

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[8] Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., p. 522, 1935.

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was computed to be 4,100 gallons per day per foot. The water-level fluctuations in the observation wells did not indicate conclusively the effect of pumping well K-2, and therefore the transmissibility could not be computed by the Theis[9] nonequilibrium method.

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[9] Op. cit., pp. 519-524.

Springs

Ten springs discharge into the wash within 3 miles of Keams Canyon. Records of these springs are given in table 1 and analyses of water samples are given in table 3. Part of the flow of three of the springs (K-1S, K-3S, and K-6S) is collected into a pipe line which discharges into a sump at the power house at Keams Canyon. The measured discharge into the sump on January 10, 1950, was 8 gallons per minute. Springs K-10S and K-9S (table 1) supply water for the Keams Canyon Trading Post and the Baptist Church, respectively. Spring K-5S is used to supply one family and to irrigate about an acre of land. The discharge from the remaining springs is not used, and constitutes the principal source of recharge to the alluvium.

It became apparent during the investigation that additional water issues from the lower member of the Mesaverde formation into the alluvium beneath the land surface. In January 1950 the visible discharge of the springs upstream from the pumped wells did not exceed 75 gallons per minute, although the surface flow of the creek was at least 100 gallons per minute. Calculations of all water entering and leaving the wash indicate that during the winter subsurface inflow into the alluvium is about 65 gallons per minute.

About 1947 an earth dam was constructed across the Keams Canyon wash on a sandstone outcrop a few hundred feet upstream from spring K-78, about 3 miles northeast of Keams Canyon. During the winter of 1949-50 the reservoir became full for the first time, and it contained water until about the middle of May 1950. Mr. L. Kingsley, supervisor of water development on the Hopi Indian Reservation, reports that the seasonal decline in flow of spring K-78 was not as great in 1950 as in the years before the dam was built. Apparently, downward percolation from the reservoir is recharging the aquifers that supply the springs.

STOCK AND DOMESTIC

Wells have been drilled successfully for livestock and domestic use throughout the Keams Canyon area. In the northern part of the area flowing wells yield water from the Dakota sandstone. In other parts of the area small supplies are obtained from the alluvial fill and from the upper member of the Bidahochi formation.

QUALITY OF WATER

By J. D. Hem

The chemical character of ground water in the northern part of the Keams Canyon area is indicated by 11 analyses in table 3. Well 6M-79, 6M-80, and 7M-37 obtain water from the Dakota sandstone. On the basis of the information available, it is not possible to predict with assurance the chemical character of water in the Dakota sandstone at Keams Canyon. First, the three analyses indicate a variation from place to place in the chemical character of the water, and second, the wells are 7 to 10 miles from the community. The analyses indicate, however, that the water might not be entirely satisfactory as a public supply. Waters from wells 6M-79 and 6M-80 contained rather large amounts of sodium, sulfate, and bicarbonate, and excessive amounts of fluoride (more than 3 parts per million). It is generally recognized that waters with such high concentrations of fluoride may cause mottling of the tooth enamel in young children. Water from well 7M-37, southeast of Keams Canyon, is lower in dissolved solids than waters from wells 6M-79 and 6M-80 and does not contain objectionable amounts of fluoride. All three waters are soft.

Springs K-1S, K7S, and K-9S, for which analyses are given in table 3, issue from the lower member of the Mesaverde formation in Keams Canyon. Waters from the three springs sampled differed considerably in chemical character and dissolved solids concentration, and the spring having the highest discharge had the highest dissolved solids concentration. The cause of these differences in composition is not known, but they may be related to lack of uniformity in the soluble components of the Mesaverde formation in this area. These waters are moderately hard to very hard but otherwise are not objectionably high in concentration of dissolved solids.

Wells 7M-26, 7M-33, and 7M-56 are reported to obtain water from alluvium along Jeddito Wash. Waters from the first two of these wells are hard and they have moderate dissolved-solids concentration. Water from well 7M-56 contained 136 parts per million of dissolved solids, the lowest of any of the samples collected in the area.

Water in wells K-2 and 6M-1 is derived from alluvium in Keams Canyon. Well K-2 is one of those providing the present supply for the community. Water from this well has a moderate concentration of dissolved solids but is very hard. Well 6M-1, about 2 miles downstream from well K-2, yields somewhat softer water that is slightly lower in dissolved solids concentration. However, the water is harder than is desirable for most domestic uses. It has been noted that the alluvium is recharged principally by springs issuing from the Mesaverde formation. It appears that the analyses available are not representative of all the water entering the alluvium, as the chloride concentration in water from well K-2 is higher than in any of the springs sampled. However, the dissolved solids concentration of the well water lies between the maximum and minimum concentrations of water from the springs.

On the basis of the concentration of dissolved solids, ground water in the alluvium, although very hard, is otherwise considered satisfactory as a public supply. If a ground-water dam were constructed in the alluvium at Keams Canyon, the additional water obtained would probably be similar in quality to that of the present supply. If the phreatophytes along the wash were destroyed in order further to increase the available supply, the quality of the ground water in the alluvium probably would eventually be somewhat improved. Transpiration by phreatophytes tends to increase the concentration of dissolved solids in the residual water, and the destruction of the plants would remove the cause of this increase.

There are no data available to indicate the quality of water that might be encountered below the Dakota sandstone in this area.

POSSIBILITIES FOR DEVELOPING ADDITIONAL WATER AT KEAMS CANYON

PIPE LINE FROM SPRINGS TO KEAMS CANYON

Two adverse factors were apparent in considering the advisability of constructing a pipe line, as a supplementary water supply, from the uppermost spring to Keams Canyon. First, a pipe line would be expensive to construct and maintain, and extensive development would be needed at each of the springs. Second, a pipe line would collect only surface flow of the springs, and underground seepage would not be recovered.

A pipe line was used at one time to collect water from all the springs, and it was reported that maintenance was extremely difficult. Floods washed the line away occasionally, and freezing weather in winter caused leaks. It was concluded by the writers that reestablishing a pipe line would not be the most practicable method of obtaining additional water for Keams Canyon.

ADDITIONAL WELL IN ALLUVIUM

In determing the advisability of constructing an additional well in the alluvial fill of the wash, two factors had to be considered: (1)

The well could not be constructed downstream from the existing wells because of the danger of contamination from sewage wastes discharged into the wash. (2) A well could not be constructed too close to the existing wells without mutual interference of the cones of depression.

A site for a test well was tentatively selected, but an electrical resistivity survey indicated insufficient alluvium beneath the water table at the site to warrant drilling the well. No other location appeared to be feasible.

GROUND-WATER DAM AND INFILTRATION GALLERY

Within the past few years a new technique has been developed for preventing the movement of ground water through permeable materials.[10] The

10/ Blakeley, L. E., and Endersby, V. A., Prevention of underground leakage: Jour. Am. Water Works Assoc., vol. 40, no. 8, pp. 873-882, 1948

method consists of impregnating the aquifer with a fluid which reacts with the ground water to form an impermeable barrier. The technique is well adapted to the construction of ground-water dams. In applying the process at Keams Canyon a line of wells would be driven through the alluvium across the width of the canyon. The distance between wells would depend upon the permeability of the alluvium. The fluid is injected into each well under sufficient pressure to force it outward into the aquifer. As the injection proceeds the pipe is retracted by stages.

An alternate method of reducing underflow in the wash at Keams Canyon is to drive interlocking sheet piling through the alluvial fill to form a ground-water dam.

After investigating the relative merits of the two possible methods of stopping underflow, officials of the Hopi Agency have decided that the fluid-injection process is cheaper and is likely to be as successful as the sheet-piling method.

In evaluating the merits of increasing the yield from the alluvium by stopping underflow, rough calculations were made of the total supply available and the total discharge. The results of these calculations are given in table 4. The average produced for community use is based on measured pump discharges and reported periods of pumping, plus the flow of the three small springs from which water is collected into the pipe line. The underflow was computed from the following: The coefficient of transmissibility as determined from the pumping test, the average width of alluvial fill at the water table as determined from the cross section (fig. 2), and the gradient of the water table as determined by plane-table survey. The assured average surface flow was determined by measurements in the winter and spring. It is reported that flow occurs in the summer for only short periods after heavy rains. The use by transpiration and evaporation was estimated as follows: Area, 30 acres; annual use, based on average of 5 acre-feet per acre at lower altitudes, estimated to be 2 acre-feet per acre; length of growing season, 165 days, during which transpiration occurs at a lower than average rate for about 30 days. The figures for transpiration and evaporation are believed to be conservative, and the actual use may be greater than estimated. The lower part of table 4 represents inflow to the alluvium; the computed subsurface inflow is based on the estimated total daily use as given in the upper part of the table. It is apparent that inflow is less than total use during the summer because the water table is reported to decline each summer when the creek ceases to flow. When the creek is dry and the water table is declining, the difference between total inflow and total outflow is made up by a reduction in the quantity of ground water stored in the alluvium.

If an underflow dam is constructed it will be essential that the loss by transpiration be stopped by permanently removing all the phreatophytes between the dam and the springs upstream. It is likely that an infiltration gallery need not be constructed because, by installing larger pumps and lowering the pumping level, more water can be pumped from the existing wells than is now produced.

The exact amount of additional water that can be developed by constructing an underflow dam and destroying the phreatophytes is not known, but it is probably a substantial quantity. Measurements of the amount pumped, the discharge of the springs, and the discharge of the wash should be continued to determine whether the desired 150,000 gallons per day is available perennially.

DEEP TEST HOLE

If, after following the suggestions regarding development of water from the alluvium, additional water is desired for further expansion of the community, a test hole should be drilled to determine the productivity of the deeper aquifers. It would be desirable to drill the well several hundred feet into the Coconino sandstone. Table 5 indicates the approximate depth to the base of each of the formations that would be penetrated by the well.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made for the development of an adequate water supply for the community of Keams Canyon:

1. About 150,000 gallons per day of potable water will be needed at Keams Canyon after the community is enlarged to a total population of 1,000.

2. The existing water supply consists of three springs and two wells. The springs flow continuously and by pumping the wells 14 hours per day a total of 46,000 gallons per day can be obtained. The water, obtained from alluvial fill, is very hard but is considered otherwise suitable, with respect to mineral constituents, for use as a public supply.

3. Four possible methods of developing additional water have been considered:

a) Constructing a pipe line to a series of springs upstream;

b) Constructing an additional well in the alluvial fill;

c) Constructing a ground-water dam across the alluvial fill;

d) Drilling and development of a deep well.

The first two methods are considered not feasible.

4. It is recommended that underflow in the alluvium be reduced by constructing a ground-water dam. Transpiration in the area between the proposed dam and the springs upstream should be stopped by permanently removing the phreatophytes along the wash. It is believed that sufficient water to meet the increased demand could be developed by following these recommendations. The additional water that would be developed is expected to be similar in quality to the water now being used.

5. If additional water is needed for further expansion of the community' a test hole should be drilled to determine the water-bearing possibilities

of the Coconino sandstone. The required depth of hole would be 3,500 to 3,800 feet. Samples of drill cuttings should be collected at 10-foot intervals, and water samples should be collected from each water-bearing bed and analyzed.

Table 1. - Records of wells and springs in Keams Canyon area, Navajo County, Ariz.
(All wells are drilled unless otherwise noted in "Remarks" column)

Office number	Distance from Keams Canyon (miles)	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)
6M-175	14½ NE.	Navajo Service	---	---	---	---	---
d/6M-79	10 N.	do.	- Kear	1921	---	570	3½
d/6M-80	7½ NW.	do.	do.	1921	---	473	6
6M-2	3 W.	do.	---	---	6,137.9	80	6
6K-303	0	do.	Paul Dunning	1938	6,207.4	115	8 5/8
d/K-2	0	do.	Burt Cravath	1946	6,205.5	106	8 5/8
K-3	0	do.	---	1943	6,21[illegible].5	50	120
K-85	0	do.	---	1915	6,190	1,288	---
d/K-18	½ N.	do.	---	---	---	---	---

a/ Measuring point was usually top of casing or top of pipe clamp.
b/ C, cylinder.

Records obtained by H. A. Yashe and G. A. Repenning

Office number	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temperature (°F.)	Remarks
6M-175	---	---	C,W	S	---	No record available.
6M-79	Flows	May 5, 1950	None	S	59	Reported flow when drilled, 3½ gallons per minute. Measured flow, May 5, 1950, 1 gallon per minute. See log.
6M-80	do.	do.	do.	S	60	Reported flow when drilled, 5 gallons per minute. Measured flow, May 5, 1950, 8½ gallons per minute. See log.
6M-2	---	---	C,W	D,S	55	Depth reported. In alluvial fill along wash.
6K-303	39.74	Jan. 11, 1950	C,G,5	P	---	Downstream well of two producing wells at Keams Canyon. In alluvial fill of wash. Measured discharge, Jan. 10, 1950, 17 gallons per minute. See log.
K-2	36.03	do.	C,G,5	P	51	Upstream well of two producing wells at Keams Canyon. In alluvial fill of wash. Measured discharge, Jan. 10, 1950, 25 gallons per minute. See log.
K-3	27.98	do.	None	N	---	Abandoned infiltration gallery and sump at Keams Canyon. In alluvial fill of wash.
K-85	---	---	do.	N	---	Abandoned test hole at Keams Canyon. See log.
K-18	Flows	---	do.	P	---	Spring; estimated discharge, Jan. 17, 1950, 10 gallons per minute. Pipe line collects 8 gallons per minute from this spring and from spring K-38 for use at Keams Canyon. Issues fro[m] south side of wash.

c/ D, domestic; I, irrigation; N, not used; P, public supply; S, stock.
d/ See table 3 for analysis of water sample.
e/ Water level reported.

Table 1. - Records of wells and springs in Keams Canyon area, Navajo County, Ariz.
(All wells are drilled unless otherwise noted in "Remarks" column)

Office number	Distance from Keams Canyon (miles)	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)
K-2S	1½ E.	Navajo Service	---	---	---	---	---
K-3S	1¼ E.	do.	---	---	---	---	---
K-4S	1½ W.	do.	---	---	---	---	---
K-5S	0	do.	---	---	---	---	---
K-6S	1½ E.	do.	---	---	---	---	---
d/K-7S	2 3/4 E.	do.	---	---	6,375.4	---	---
K-8S	¼ SE.	do.	---	---	---	---	---
d/K-9S	3/4 W.	Baptist Church	---	---	---	---	---
K-10S	1 W.	McGee Trading Post	---	---	---	---	---
d/6M-1	0 SE.	Navajo Service	---	---	---	---	8
d/7M-26	5 SE.	do.	---	---	---	---	48

Office number	Water level: Depth below measuring point (feet) a/	Water level: Date of measurement	Pump and power b/	Use of water c/	Temperature (°F.)	Remarks
K-2S	Flows	---	None	N	---	Spring; estimated discharge, Jan. 17, 1950, 5 gallons per minute. Issues from south side of wash.
K-3S	do.	---	do.	P	---	Spring; discharge, Jan. 17, 1950, more than 10 gallons per minute. Issues from south side of wash.
K-4S	do.	---	do.	S	---	Spring; estimated discharge, Jan. 17, 1950, 1 gallon per minute. Issues from north side of wash.
K-5S	do.	---	do.	D,I	---	Spring; estimated discharge, Jan. 17, 1950, 3 gallons per minute. Issues from south side of wash.
K-6S	do.	---	do.	P,I	---	Spring; used partly for irrigation and partly to supply Keams Canyon. Could not measure discharge. Issues from north side of wash.
K-7S	do.	---	do.	S	53	Spring; measured discharge, Jan. 17, 1950, 50 gallons per minute. Issues from south side of wash.
K-8S	do.	---	do.	S	---	Spring; estimated discharge, Jan. 17, 1950, 15 gallons per minute. Issues in side canyon, south side of main wash.
K-9S	do.	---	do.	D	---	Spring; developed by tunneling 50 feet into canyon wall. Sealed; could not determine discharge.
K-10S	do.	---	do.	D	---	Spring; estimated discharge, Jan. 17, 1950, 2 gallons per minute.
6M-1	---	---	C,W	D,S	---	
7M-26	8.75	Apr. 27, 1950	C,H	D,S	54	Dug well, ½ mile northeast of Jeddito Trading Post.

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Table 1. - Records of wells and springs in Keams Canyon area, Navajo County, Ariz.
(All wells are drilled unless otherwise noted in "Remarks" column)

Office number	Distance from Keams Canyon (miles)	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (inches)
78-33	4 3/4	W. G. Roberts	---	---	---	---	48
a/78-56	5½ S.	Navajo Service	---	---	---	---	48
a/78-37	8½ SE.	do.	- Kersey	1934	---	920	6 5/8
78-15	7½ SE.	do.	- Kersey	1936	---	933	8
78-52	16 SE	do.	- Kersey	1934	---	424	8 5/8
78-45	18 S.	do.	- Kersey	1936	---	270	6¼

Office number	Water level		Pump and power b/	Use of water c/	Temperature (°F.)	Remarks
	Depth below measuring point (feet) a/	Date of measurement				
7M-33	4.30	Apr. 27, 1950	C,N	D,S	54	Dug well at Jeddito Trading Post.
7M-56	3.45	do.	C,H	D,S	50	Dug well.
7M-37	584	(e)	C,W	D,S	62	See log.
7M-15	721	(e)	C,W	D,S	---	Do.
7M-52	126	(e)	C,W	D,S	---	Do.
7M-45	102	(e)	C,W	D,S	---	Do.

Table 7. - Drillers' logs of wells in Keams Canyon area, Navajo County, Ariz.

	Thickness (feet)	Depth (feet)
Well 6M-79		
Alluvium (Quaternary)		
Soil and clay	62	62
Mud and gravel	3	65
Yellow clay	15	80
Mancos shale (Cretaceous)		
Black shale	248	328
Sandstone; water rose to 310 feet	2	330
Tough gray shale	20	350
Dakota sandstone (Cretaceous)		
Sandstone	12	362
Black shale	9	371
"Dirty" sandstone	18	389
Coal and tough shale	21	410
Gray shale	20	430
Sandstone	2	432
Coal	11	443
Fire clay	2	445
"Dirty" sandstone	5	450
Sandstone; water flowing 200 gal. per hr.	28	478
Morrison formation (Jurassic)		
"Chalk"	92	570
TOTAL DEPTH		570

	Thickness (feet)	Depth (feet)
Well 6M-80		
Alluvium (Quaternary)		
Soil	40	40
Sand	20	60
Sand and gravel; water	25	85
Mancos shale (Cretaceous)		
Black shale	125	210
Gray shale	5	215
Black shale	170	385
Dakota sandstone (Cretaceous		
Sandstone; some water	35	420
Black shale	20	440
Sandstone; water flowing 5 gal. per min.	28	468
Coal	4	472
Gray clay	1	473
TOTAL DEPTH		473

Cased to total depth; perforated from 442 to 468 feet.

	Thickness (feet)	Depth (feet)
Partial log, well 6K-303		
Alluvium (Quaternary)		
Old caisson	43	43
Fine-grained sand	7	50
Clay	25	75
Fine-grained sand and gravel	10	85
Black shale	30	115
TOTAL DEPTH		115

Cased to total depth; perforated from 83 to 87 feet; gravel packed around casing.

	Thickness (feet)	Depth (feet)
Well K-2		
Alluvium (Quaternary)		
Clay	6	6
"Alluvium"	28	34
Fine-grained sand; water	14	48
Clay	2	50
Sand; water	10	60
Sand and gravel; water, wood fragments	23	83
Coal with layers of black shale	14	97
Light-colored shale	9	106
TOTAL DEPTH		106

Casing record; 8 5/8-inch casing to 88½ feet; perforated from 42 to 86 feet; gravel-packed, 20 to 88½ feet.

Table 2. - Drillers' logs of wells in Keams Canyon area, Navajo County, Ariz.

	Thickness (feet)	Depth (feet)
Reported driller's log of well K-65, copied from graphic log:10/		
Alluvium (Quaternary)		
Surface material; water	72	72
Mancos shale (Cretaceous)		
Shale	517	589
Shale with fossils	22	611
Shale	72	683
Black shale	6	689
Shale	311	1,000
Black and red shale	22	1,022
Shale	22	1,044
Brown shale	26	1,070
Dakota sandstone (Cretaceous)		
Brown sandstone; water	30	1,100
Morrison formation (Jurassic)		
Light-gray sandstone	22	1,122
Light-red sandstone and green-white shale	78	1,200
Light-red sandstone	65	1,265
TOTAL DEPTH		1,265
Well 78-37		
Alluvium (Quaternary)		
Surface soil	2	2
Bidahochi formation (Tertiary)		
Soft red sand	15	17
Soft gray sand	313	330
Mesaverde formation (Cretaceous)		
Soft yellow sand	50	380
Yellow sand	31	411
"Quicksand"	9	420
Coarse-grained white sand	12	432
Mancos shale (Cretaceous)		
Blue shale	206	638
Soft dark-colored shale	170	808
Dakota sandstone (Cretaceous)		
Soft gray sand	4	812
Well 78-37--Con.		
Dakota sandstone (Cretaceous)--Con.		
Dark-colored shale	28	840
Light-colored sand	9	849
Black shale	11	860
Coal	2	862
Black shale and coal	8	875
Black shale	26	902
Gray sand; water	18	920
TOTAL DEPTH		920
Well 78-15		
Bidahochi formation (Tertiary)		
Sand	345	345
Bentonitic clay	45	390
Mancos shale (Cretaceous)		
Gray shale	435	825
Gray sand	25	850
Dark-colored shale	35	885
Dakota sandstone (Cretaceous)		
Water sand	20	905
Black shale	28	933
TOTAL DEPTH		933
Well 78-52		
Alluvium (Quaternary)		
Soil	10	10
Bidahochi formation (Tertiary)		
Gray sandstone	70	80
Gray shale	25	105
Mancos shale (Cretaceous)		
Blue shale	5	110
Gray shale	20	130
Red shale	20	150
Gray shale	25	175
Red mud	25	200
Gray shale	5	205
Red mud	40	245
Gray mud	35	280
Gray sand; water	138	418
Light-colored shale	6	424
TOTAL DEPTH		424

10/ 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, p. 176, 1916.

Table 2. - Drillers' logs of wells in Keams Canyon area, Navajo County, Ariz.

	Thickness (feet)	Depth (feet)
Well 7K-45		
Bidahochi formation (Tertiary)		
Soft red sand	50	50
Gravel and conglomerate	2	52
Mancos shale (Cretaceous)		
Blue shale	106	158
Dakota sandstone (Cretaceous)		
Coal	5	163
Gray sand	49	212
Water sand	26	238
Blue shale	27	265
Morrison formation (Jurassic)		
Water sand	5	270
TOTAL DEPTH		270

Table 3. - Analyses of water from wells and springs in Keams Canyon area, Navajo County, Ariz.
(Parts per million except specific conductance.)
(Numbers correspond to numbers in tables 1 and 2.)

Well or spring no.	Date of collection, 1950	Specific conductance (micromhos at 25°C.)	Silica (SiO_2)	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 $CaCO_3$
6N-79	May 5	1,720	9.6	3.2	1.6	410	524	395	38	3.9	0.2	1,120	14
6N-80	do.	1,810	10	5.0	1.3	431	512	445	44	3.5	.2	1,190	18
6N-2	May 4	779	19	66	20	83	268	160	11	.8	30	522	246
K-2	Jan. 10	912	16	111	30	22	358	134	33	.6	1.9	544	400
a/K-18	do.	418	23	56	7.5	21	187	30	14	.2	16	260	170
K-75	Jan. 16	1,070	21	175	30	21	337	261	26	.3	26	726	560
K-98	Jan. 17	494	18	85	21	11	291	77	11	.2	.3	366	298
7N-26	Apr. 27	514	16	72	11	24	255	28	16	.6	18	312	224
7N-33	do.	324	18	45	12	5.8	185	18	2	.6	.1	190	162
7N-56	do.	215	17	28	5.4	10	114	13	2	.8	3.4	136	92
7N-37	do.	1,190	7.9	2.0	1.0	270	277	333	14	1.0	.2	765	9

a/ Combined flow of springs K-18 and K-38.

Table 4. - Estimated average daily use of water at Keams Canyon and estimated daily supply, 1950

Estimated daily disposal of water, in gallons per minute

Season	Average produced for community use	Average underflow	Average surface flow	Average transpiration and evaporation	Total
Winter	a/ 20	b/ 20	a/ 100	b/ 0	140
Spring and fall	b/ 30	b/ 20	a/ 30	b/ 50	130
Summer	b/ 30	a/ 10	a/ 0	b/ 90	130

Estimated daily supply available, in gallons per minute

Season	Surface discharge of springs	Subsurface inflow	Total
Winter	a/ 75	b/ 65	140
Spring and fall	a/ 70	b/ 60	130
Summer	c/ 50	c/ 50	d/ 100

a/ Measured.
b/ Computed.
c/ Estimated.
d/ Supply may be less than demand in summer; difference must be made up from ground-water storage, and must be replenished during periods when supply exceeds demand.

Table 5.--Formations that would be penetrated in a deep test hole at Keams Canyon.

Formation	Age	Water-Bearing character	Thickness (feet)	Depth to base of formation (feet)
Mancos shale	Upper Cretaceous	Non-water-bearing	1,070	1,070
Dakota sandstone	do.	Water-bearing	25	1,095
Morrison formation	Upper Jurassic	Probably water-bearing a/	200	1,295
Carmel formation	Upper and Middle Jurassic	Probably non-water-bearing	215	1,510
Wingate sandstone	Jurassic (?)	do.	700-800	2,210-2,310
Chinle formation	Upper Triassic	Non-water-bearing	900-1,000	3,110-3,310
Shinarump conglomerate	do.	Water-bearing a/	50	3,160-3,360
Moenkopi formation	Lower Triassic	Non-water-bearing	150-250	3,310-3,610
Coconino sandstone	Permian	Water-bearing	400-700	3,710-4,310

a/ Water may have high content of dissolved solids.