WATER-SUPPLY INVESTIGATION OF THE BUELL PARK-SAWMILL AREA, NAVAJO INDIAN RESERVATION, APACHE COUNTY, ARIZONA

By

J. D. Hem

OFR 50-107

A. N. Sayre, Washington, D. C. April 20, 1950
Through S. F. Turner
H. A. Whitcomb, Tucson, Arizona

Transmittal of report: "Water-supply investigation of the Buell Park-Sawmill area, Navajo Indian Reservation, Apache County, Arizona."

I enclose the original and one carbon copy of this report for editing, for release first to the Office of Indian Affairs and later to the open file.

Copies of the report are being sent for review to Messrs. Theis, Howard, Hem, and Read. They have been requested to send their criticisms directly to Washington.

Harold A. Whitcomb

Harold A. Whitcomb
Geologist

cc: C. V. Theis
J. D. Hem
C. S. Howard
C. B. Read

United States

Department of the Interior

Geological Survey

Released to open file
"See letter stamped
8/24/50 in San Juan Co. file"

Water-supply investigation of the Buell Park-Sawmill area, Navajo Indian Reservation, Apache County, Arizona

By
H. A. Whitcomb and L. C. Halpenny
With a section on
Quality of water
By
J. D. Hem

Tucson, Arizona
April 1950

CONTENTS

TABLES

ILLUSTRATIONS

INTRODUCTION

The Buell Park-Sawmill area was studied by the Ground Water Branch of the Geological Survey in 1948-49, in an effort to locate additional water supplies. The work was part of a program which includes a reconnaissance investigation of the ground-water resources of the Navajo and Hopi Indian Reservations and special studies in areas where specific problems require immediate attention.

The work in the Buell Park-Sawmill area was begun in order to determine if springs in Buell Park could be developed as a supplemental supply for a proposed school near Fort Defiance. At the request of the Navajo Service, the scope of the investigation was enlarged to include the area near the Navajo Tribal Sawmill, 3 miles west of Buell Park. Expansion of the Sawmill is contemplated, which will create a demand for additional water. Because the Buell Park and Sawmill areas are contiguous, the results of both investigations are included in this report.

Location

The Buell Park-Sawmill area is located near the crest of the Defiance uplift, on the eastern margin of the Defiance Plateau, in Apache County, Arizona. The altitude at the Sawmill is about 7,600 feet, and in Buell Park, about 7,200 feet. An improved gravel road connects the Sawmill with Fort Defiance, 13 miles to the south. Buell Park can be reached by wagon trails from the Sawmill-Fort Defiance road and the Black Creek Valley road (see pl. 1).

Topography and drainage

The Defiance Plateau is a high table land extending for nearly 100 miles along the eastern border of northern Arizona. To the east the plateau terminates in a long, regular, rather steep dip slope which forms the western wall of Black Creek Valley. The Defiance Plateau slopes gently westward to Chinle Valley.

The topography of the Buell Park-Sawmill area is characteristically flat or gently rolling. Locally, the surface has been dissected by eastward flowing streams, as at Buell Park and at Bonito Canyon near Fort Defiance.

Buell Park is a circular depression, approximately 3 miles in diameter, on the extreme eastern edge of the Defiance Plateau. This natural amphitheater is sunk into massive sandstones whose sheer, salmon-pink walls rim the valley on the north and east. To the south and west, forested, yet rather precipitous, slopes reflect the presence of softer strata. The floor of Buell Park is flat, grass-covered, and fringed by scattered growths of ponderosa and pinon pine.

Peridot Creek flows eastward through the park, and has breached the walls in two places. The creek enters on the western side, through a deep, narrow canyon. A second canyon of much smaller proportions provides an eastern exit. Within the park, the stream is entrenched. Three springs, issuing from the valley floor, provide a perennial flow to the creek.

Climate

No records of the temperature or rainfall in the Buell Park-Sawmill area are available. According to records of the U. S. Weather Bureau, collected at Fort Defiance, which is the nearest station and has an altitude of 6,850 feet, the mean annual temperature is 49 degrees Fahrenheit. The precipitation at Fort Defiance is 13 inches a year, including 40 inches of snow. As the altitude at Sawmill is about 7,600 feet, or 750 feet higher than at Fort Defiance, it is probable that the mean annual temperature is lower and the annual precipitation is higher at the Sawmill than at Fort Defiance. Summers are cool and winters are usually severe, with heavy snows. The area is in the vegetation zone of the ponderosa pine, which supplies the timber for the Sawmill.

Summary of problems

Two problems were considered during the investigation.

The first problem was to determine whether the springs in Buell Park could be developed as a supply for a proposed school and community with a total population of about 1,800. Assuming a daily rate of use of 150 gallons per person, a continuous supply of about 180 gallons per minute would be needed. An investigation of the Fort Defiance area1/ showed that springs in that area would yield barely sufficient water to supply the existing community and the proposed new school. After visiting Buell Park, officials of the Navajo Service suggested that the school be built there rather than near Fort Defiance, provided that sufficient water could be developed.

The second problem considered during the investigation was to determine whether sufficient water would be available to warrant enlargement of the Tribal Sawmill. It was estimated by R. H. Rupkey2/ in 1946 that the average water requirement at the Sawmill was 55,000 gallons per day, including mill operations and domestic consumption. The water requirement after enlargement of the mill and community was estimated to be 180,000 gallons per day3/, equivalent to a continuous supply of about 125 gallons per minute. The report states that the existing supplies would yield a minimum of about 50,000 gallons per day, and that sufficient additional water could be developed in the area to warrant expansion of the Sawmill. The anticipated expansion had not

1/ Halpenny, L. C., and Brown, S. C., Water-supply investigation of Fort Defiance area, Navajo Indian Reservation, Apache County, Arizona: U. S. Geol. Survey (mimeographed), p. 10, March 1949.

2/ Rupkey, R. H., Water supply, Navajo Tribal Sawmill, Navajo Indian Reservation: Office of Indian Affairs (typewritten), p. 3, July 12, 1946.

3/ Idem (Rupkey, R. H., op. cit.), p. 5.

occurred at the time the Geological Survey was investigating the water supplies in Buell Park, and the authors of this paper were requested to expand the scope of their investigation to include the Sawmill area.

A preliminary report on the Sawmill area[4] was prepared before the investigation was completed. The conclusions given in the preliminary report have not been changed as a result of completion of the field work.

Field work and acknowledgments

Field work was begun in the late fall of 1948, but was interrupted by unusually heavy snows during January and February 1949 and by the resulting heavy runoff during the early part of March. The field work was completed in the late spring of 1949 with the exception of a program of periodic measurements of the discharge of each of the springs in the area.

Field work included a study of the geologic structure and stratigraphy of the region and the preparation of a geologic map (pl. 1). The discharge of each spring in the area was measured, and a pumping test was made on the Sawmill school well. The altitude of each well and spring was determined from a plane-table traverse (see table 1). Water samples were collected, and were analyzed in the laboratory of the Quality of Water Branch, Albuquerque, New Mexico.

Field work was done by H. A. Whitcomb, geologist, L. C. Halpenny, engineer, and R. J. Drake, engineering aide. S. F. Turner, district engineer for ground-water investigations in Arizona, reviewed the field work and the report. C. B. Read, in charge of the Albuquerque office of the Fuels Branch, Geologic Division, reviewed the field work and the report with respect to stratigraphy. J. D. Hem, district chemist of the Quality of Water Branch, wrote the section on quality of water.

4/ Halpenny, L. C., and Whitcomb, H. A., Memorandum on status of water-supply investigation of Sawmill area, Navajo Indian Reservation, Apache County, Arizona: U. S. Geol. Survey (typewritten), 3 pp., April 1949.

GEOLOGY AND GROUND-WATER RESOURCES

The stratigraphic section exposed in the region is as follows:

QUATERNARY	Recent alluvium
CRETACEOUS	Dakota (?) sandstone
JURASSIC	Morrison formation San Rafael group
JURASSIC (?)	Glen Canyon group
TRIASSIC	Chinle formation Shinarump conglomerate
PERMIAN	Upper member of Cutler formation Lower member of Cutler formation
PRE-CAMBRIAN (?)	Quartzite

Of these rock units, all but the quartzite are exposed in the area shown on the accompanying geologic map (pl. 1). The quartzite is exposed in Bonito Canyon[5], a few miles south of the Tribal Sawmill.

Sedimentary rocks and their water-bearing properties

Pre-Cambrian (?) rocks

In Bonito Canyon, about 8 miles south of the Sawmill, Permian strata rest unconformably upon pre-Cambrian (?) quartzite. It is believed that the quartzite also occurs in the Buell Park-Sawmill area, as a "very hard gray sandstone" was encountered at 784 feet in a dry well drilled at the Sawmill in 1942 (see table 2). No drill cuttings from this well are available for examination.

The quartzite in Bonito Canyon is a dark-gray, generally fine-grained, massive rock which commonly shows small-scale cross-bedding and ripple marks. Occasional thin conglomeratic lenses are irregularly distributed. Where the contacts with the overlying Permian shales were observed the quartzite displays an irregular but smoothly rounded surface.

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. 17, 1917.

The quartzite exposed in Bonito Canyon is not water bearing, and the quartzite (?) encountered in the deep well at the Sawmill did not yield water.

Permian rocks

Lower member of Cutler formation

The Permian rocks cropping out in the wall of Buell Park are correlated with the Cutler formation of Monument Valley, Utah. The red beds which crop out at the base of the section in the northern and southern walls consist of about 200 feet of dark-red, medium-grained, soft, thin-bedded sandstone with shaly partings. These outcrops characteristically form precipitous, dark-red, debris and vegetation-covered slopes. C. B. Read[6] of the Geologic Division suggests that the red beds exposed at Buell Park may be considered the equivalent of the Lower Supai formation of the Mogollon Rim of Arizona, the Mesita Blanca member of the Yeso formation of New Mexico, or the lower part of the Cutler formation of Monument Valley, Utah. In this paper the redbeds are designated as the lower member of the Cutler formation.

Springs issue from joints and along bedding planes in the lower member of the Cutler formation. Morgan Spring (BP-6, table 1) is a perennial spring south of the Sawmill. Springs BP-10 and BP-11 (table 1) also issue from these rocks. The rocks did not yield water to the deep well at the Sawmill.

Upper member of Cutler formation

The massive sandstone which overlies the lower member of the Cutler formation with apparent conformity rises abruptly to form a sheer cliff nearly 350 feet high. It is correlated with the DeChelly sandstone member of the Cutler formation and is designated in this report as the upper member of the Cutler formation. In Buell Park the upper member of the Cutler formation is readily

6/ Read, C. B., personal communication, Dec. 10, 1948.

separable into two distinct units. The lower 250 feet consists of orange-pink, fine-grained, rather hard, massive sandstone exhibiting on its weathered surfaces large-scale tangential cross-bedding. The upper 100 feet consists of gray-brown, fine-to-medium-grained, hard, relatively thin-bedded and blocky sandstone laid down in alternating flat- and cross-bedded strata. The cross-bedding is characteristically of a rather flat sweeping nature, consisting of long, thin, curved, parallel laminae sharply truncated at the top and tangential to a horizontal surface at the bottom. The cross-bedding is remarkably uniform throughout each bed in which it occurs.

One spring issues from the upper member of the Cutler formation in the Buell Park-Sawmill area (BP-7, table 1). Several springs west of the area issue from the upper part of the member. In April 1949, part of the discharge of spring BP-10 was derived from seepage out of the upper member of the Cutler formation.

Triassic rocks

Shinarump conglomerate

The upper (?) Triassic Shinarump conglomerate disconformably overlies the upper member of the Cutler formation in the absence of the Moenkopi formation, which is not recognized on the Defiance uplift. The Shinarump conglomerate caps the rim of the Buell Park basin on the north and east, and forms the dip-slope surface of the eastern side of the Defiance uplift. Farther east, the conglomerate disappears beneath the Upper Triassic Chinle shales, which occupy the broad Black Creek Valley. The thickness of the Shinarump conglomerate has been reduced by erosion to a maximum of 80 feet on the eastern rim of Buell Park, leaving only the basal coarse sandstone, which locally contains conglomeratic lenses. The conglomerate consists predominantly of quartz and quartzite pebbles, but rounded fragments of chert, limestone, and petrified wood occur locally. The predominant color of the formation is light gray.

The Shinarump conglomerate probably is water bearing in Black Creek Valley, as the large outcrop area is ideally situated to receive recharge. Water in the formation in this area is likely to be under artesian pressure. No wells have been drilled to the Shinarump conglomerate in the area described in this report.

Chinle formation

The Chinle formation conformably overlies the Shinarump conglomerate and is composed primarily of alternating beds of soft, pink, purple, and gray shales that weather readily into smooth clay-covered slopes and rounded knobs and ridges. Intercalated with the shales are several relatively thin beds of sandstone and an occasional thin bed of cherty limestone. Three major sandstone units, ranging in thickness from 15 to 30 feet, extend as parallel ridges for several miles along the floor of Black Creek Valley from the vicinity of Window Rock to a point some distance north of Fort Defiance. The sandstones are commonly coarse grained and are conglomeratic in places. The entire Chinle formation is approximately 1,500 feet thick in Black Creek Valley.

In most areas the Chinle formation yields limited amounts of water that is fairly high in dissolved mineral content. The water-bearing character of the formation in this part of Black Creek Valley is unknown, but it is believed that the sandstone members would yield water to wells in limited quantities.

Jurassic and Cretaceous rocks

The stratified rocks overlying the Chinle formation include the Glen Canyon group of Jurassic (?) age, the San Rafael group and the Morrison formation, of Jurassic age, and the Dakota (?) sandstone of Cretaceous age. These rocks crop out only on the high ridge east of Black Creek Valley and dip toward the east.

The Jurassic and Cretaceous rocks are not considered as possible sources of water for the Buell Park-Sawmill area, because they lie at too great a distance and dip away from the area. For these reasons, any water that might be found in these rocks would be costly to develop and utilize as a supply for the Buell Park-Sawmill area. Small supplies probably could be developed farther east for local domestic and stock use, however, particularly from the Dakota (?) sandstone and the massive sandstone member of the San Rafael group.

Quaternary alluvium

The surface of the Defiance Plateau is covered by a thin layer of sandy soil ranging in thickness from a few inches on the slopes to approximately 15 feet at the Tribal Sawmill. These deposits are of Quaternary age. The floor of Buell Park is comprised of fine sand and silt ranging in thickness from a few inches to a maximum of 26 feet. These deposits are probably of Recent age. There is evidence to suggest that several cycles of alluviation and erosion have occurred prior to the present stage of downcutting. Recent alluvium of unknown thickness, consisting of fine sand, silt, and clay, is exposed along the course of Black Creek.

The alluvium in the Sawmill area is the source of water for both the industrial supply and the school well (BP-4 and BP-5, table 1). The three abandoned wells at the Sawmill (BP-8, BP-9, and 18K-306, table 1) also obtained water from this material. Springs farther upstream along the principal wash furnish a perennial supply of water to the alluvium. In Buell Park, the alluvium is not known to be water bearing except along Peridot Creek. The creek is perennial below spring BP-2 (table 1), which rises in the alluvium of the creek bed. The source of this water may, however, be volcanic agglomerate underlying the alluvium. In Black Creek Valley a few dug wells obtain water from the alluvium along ~~the~~ Black creek.

Igneous rocks and their water-bearing properties

The igneous rocks in the Buell Park-Sawmill area, with the exception of two intrusive dikes, are of volcanic origin. Gregory[7] assigned them to the Tertiary period as he did all the igneous rocks in the Navajo country. Evidence developed during the present investigation indicates only that the volcanic rocks in Buell Park are of post-Cretaceous age.

Agglomerate

A gray-green agglomerate of Tertiary (?) age underlies the alluvium in Buell Park. This agglomerate contains fragments of igneous rock and angular and rounded pebbles derived from the country rock. Most of the pebbles are small and are composed of quartzite, chert, and slate. The matrix appears to be tuffaceous and contains abundant olivine and garnet crystals. On the weathered surface the rock is light green, soft, and friable. The igneous material flanking the dike that forms Peridot Ridge, and the knob in the center of the valley, are also composed of agglomerate, but are dark brownish green and appear to be more resistant than the rock underlying the alluvium. The green color in all cases is imparted by the abundant olivine.

The agglomerate is the source of water for two of the principal springs in Buell Park (BP-1 and BP-3, table 1). These springs issue directly from the agglomerate in places where it has been cut below the water table by

---

[7] Gregory, A. E., op. cit., plate II.

erosion. East of spring BP-1 is a swampy area several acres in extent, where water stands at the surface in places. A thin layer of alluvium has been deposited over the agglomerate in this area.

It is doubtful that the springs in Buell Park derive their supply solely from recharge directly on the exposed surface of the agglomerate. Direct recharge occurs as a result of precipitation on the outcrop area and of infiltration from stream flow in the upper reaches of Peridot Creek. Recharge from these sources is considered to be insufficient to maintain the flow of the springs. It is believed, therefore, that the agglomerate filling the depression of Buell Park collects and stores water partly from the less permeable surrounding sandstone and partly from direct recharge.

Lava flows

The lavas of Sterrett Mesa and Buell Mountain (pl. 1) range from a light-gray porphyry containing phenocrysts of olivine and biotite to a black, vesicular basalt containing bombs and other pyroclastic fragments. These lavas are of Tertiary (?) age, and are remnants of flows which probably entered the area from the north. The lavas in the Buell Park-Sawmill area are not water bearing as they lie well above the water table.

Dikes

The basic dike forming the backbone of Peridot Ridge (pl. 1) parallels the south and east walls of the basin for nearly 2 miles. The dike dips away from the center of the valley at an angle of about 30°. The width ranges from 5 to 50 feet. The rock composing the dike is nearly black, very fine grained, hard, brittle, and weathers to a rusty dark gray. On the basis of field examination it is classified as diabase.

A minor dike that strikes N.15°W. from the west end of Peridot Ridge is made up of a light-gray porphyry containing phenocrysts of olivine and biotite. The biotite has a dark reddish-brown luster. This same dike or one very similar crops out in the south flank of Sterrett Mesa.

The dikes in Buell Park are not water bearing and cannot be classed as aquifers. However, the major dike has retarded downcutting of Peridot Creek, retards eastward movement of ground water in the agglomerate, and raises the water table in Buell Park. Consequently the dike is believed to be an important factor in determining the location and maintaining the flow of the principal springs.

Structure

The Defiance uplift is the major structural feature of the Buell Park-Sawmill area. The uplift has been described by Gregory[8], and by earlier visitors to the region, as a monoclinal fold that trends generally north for a distance of nearly 200 miles along the eastern border of northern Arizona. The regional structure is best observed in the walls of Buell Park and in the deep canyons cut into the dip slope of the uplift by Peridot and Bonito Creeks. Dips ranging from 10° to 15° to the east were measured in those localities.

Local structural features in the area are limited to Buell Park. The park has been described both as a volcanic vent[9] and as a cauldron subsidence[10]. The theory of volcanic origin indicates that the volcanic agglomerate grades downward into an increasingly dense igneous mass. The theory of subsidence suggests that an unknown thickness of agglomerate is underlain by a block of sandstone that, due to its greater weight, sank into the magma. There is evidence to support both theories, and only subsurface examination, by means of test holes or geophysical probes, can determine which is correct.

8/ Gregory, H. E., op. cit., p. 111.

9/ Idem (Gregory, H. E., op. cit.), p. 94.

10/ Williams, Howel, Pliocene volcanoes of the Navajo-Hopi country: Geol. Soc. America Bull., vol. 47, no. 1, pp. 141-143, January 31, 1936.

A shallow, easterly plunging syncline is evident in Buell Park. In the east wall of the park, the north limb of the syncline dips 4° to the south. The trough of the syncline is occupied by Peridot Creek. South of the creek the beds rise at an angle of 10° to form the south limb. At the axis of the syncline, the lower member of the Cutler formation and the entire lower unit of the upper member disappear beneath the surface.

The only relationships suggestive of faulting in the Buell Park-Sawmill area were found in the northwest quarter of Buell Park. There an estimated 75 to 100 feet of lava flows rest in vertical contact against the sandstone forming the wall of the park. The flow rocks dip and thicken appreciably toward the center of the park. Below the flows, a mass of agglomerate, preserved from erosion by the resistant capping, rises nearly to the rim. Pronounced slickensiding was observed in the agglomerate, in zones parallel to the sandstone walls of the park. No lava remains on the sandstone surrounding the park, although the flows must originally have covered an extensive area. It is believed that at the time the lavas flowed into the area, probably from the north, there was already a depression where the park now exists. Lavas flowed into the depression. Whether as a result of the additional load so imposed, or from some undetermined cause, the mass of agglomerate within the park area subsided, causing downfaulting of the lava flows ~~in~~ on a scale of about 100 feet.

The subterranean forces that created Buell Park produced no detectable evidence of faulting in the surrounding strata. What appears to be a slump block lies against the north wall of the valley. The block includes rocks of the upper member of the Cutler formation and the overlying Shinarump conglomerate. The strike of this slump or minor fault is roughly northeast and can be traced for several hundred feet. The disturbance appears to be relatively recent.

WATER SUPPLIES

Springs in Buell Park

The following table summarizes measurements of discharge of the three principal springs in Buell Park:

Date	Gallons per minute			
	BP-1	BP-2	BP-3	Total
Oct. 3, 1948	17	140	90	247
Apr. 14, 1949	20	178	110	308
June 5, 1949	17	192	99	308

The minimum discharge of spring BP-10 is estimated to be 20 gallons per minute, and of spring BP-11, 10 gallons per minute. These two springs need not be considered at this time as a source of water either for the Sawmill or for the proposed school.

A large number of seedling trees was planted along Peridot Creek in the spring of 1949, apparently as a means of bank protection against floods. If these plants eventually become heavy users of ground water, the water supply now available for domestic use in Buell Park will be greatly reduced.

Present Sawmill supply

Well BP-4 (see pl. 1 and table 1) now furnishes water for the steam boilers and the log pond at the Sawmill. The well consists of a sump, about 30 feet in diameter and 8 feet deep, dug into the alluvium of the principal wash in the vicinity, about 3,000 feet downstream from the mill. A low dam set on bedrock below the sump prevents underflow from moving downstream. In times of low surface flows all of the stream discharge is captured by the well, and in times of higher surface flows the excess water passes over a spillway in the underflow dam. The wash is reported to be dry about a month each year at well BP-4 but flows most of the year upstream opposite well BP-5 (pl. 1). The underflow supplying well BP-4 is derived from perennial surface flows upstream and from infiltration at the log pond.

In April 1949 the sump was being pumped at a rate of 62 gallons per minute for about 12 hours each day, equivalent to a daily rate of about 44,600 gallons. A swampy area a few hundred feet upstream from the well supports a luxuriant growth of grasses that waste ground water by transpiration. If the water table in the swamp were lowered by draining, the amount of water transpired by the plants would be reduced and the output of the well (BP-4) could be increased.

Well BP-5 (pl. 1) supplies water for the school and for the community at the Sawmill. The well has been dug in alluvial fill at the edge of a wash. A pumping test was made on this well on April 18-19, 1949. The average discharge was 29 gallons per minute and the maximum drawdown was 4.9 feet. Prior to the test the standing water level in the well was 3.74 feet below the floor of the well house, and was at an elevation approximately equal to the elevation of the creek bed. During the test, discharge measurements were made in the creek to determine if pumping the well would reduce the flow. However, a sleet storm on the day of the test produced runoff that caused a rise in the creek and made the measurements valueless. On the basis of data collected during the pumping test the coefficient of transmissibility of the aquifer was computed to be 1,800 gallons per day per square foot at unit hydraulic gradient. The gradient of the stream was determined to be 82 feet per mile, and the average width of the alluvium to be about 350 feet. On the basis of these figures, the underflow of the creek on April 18, 1949, was calculated to be about 9,800 gallons per day. The well normally was being pumped about 6 hours each day at a rate of 29 gallons per minute, which is about 10,500 gallons per day. It is obvious that pumping the well must decrease the flow of the creek. It is concluded that the minimum daily discharge that can be expected from the well is no more than 10,000 gallons per day.

Springs near Sawmill

The investigation included a study of all the springs in the Buell Park-Sawmill area. At the time this phase of the field work was being done, snow on the Defiance Plateau was melting and numerous temporary springs were noted. The two principal perennial springs outside Buell Park (BP-6 and BP-7) are described in table 1. R. H. Rupkey of the Office of Indian Affairs measured the discharge of spring BP-6 twice in 1946[11/] and found it to be 175 gallons per minute on April 8 and 80 gallons per minute on June 11. The discharge on October 25, 1948, was estimated by the authors of this paper to be about 100 gallons per minute, and on April 14, 1949, the measured discharge was 168 gallons per minute. Mr. Rupkey estimated that a minimum of 100 gallons per minute could be developed at the point where the measurements were made by capturing all the surface flow and by reducing underflow and transpiration. The later measurements made by the authors of this paper corroborate Mr. Rupkey's findings. Assuming that 100 gallons per minute could be developed from this spring, the yield would be 144,000 gallons per day.

The minimum discharge of spring BP-7 was 3 gallons per minute, measured on October 25, 1948. It is concluded that this spring is of little value as a source of water for the Sawmill.

QUALITY OF WATER

By J. D. Hem

Quality of water in relation to geologic formations

The quality of ground water in the Buell Park-Sawmill area is indicated by the analyses of 13 samples contained in table 3. The immediate source of water in wells BP-4 and BP-5 is Quaternary alluvium in the Sawmill area.

11/ Rupkey, R. H., op. cit., p. 8.

Spring BP-2, which rises in the bed of Peridot Creek, also is reported to issue from alluvium. Springs BP-1 and BP-3 issue from volcanic agglomerate in Buell Park. Spring BP-7 issues from the upper member of the Cutler formation in the Sawmill area, and springs BP-6 and BP-11 issue from the lower member of the Cutler formation. Spring BP-10, located at the contact between the upper and lower members, apparently obtains water from both members.

The water from the wells in alluvium in the vicinity of the Sawmill contains approximately 300 parts per million of dissolved solids. The water contains mostly calcium and bicarbonate and is low in silica. On the basis of the analyses available, water from the upper member of the Cutler formation is similar in chemical character to water from the alluvium. However, the two available samples have a rather wide range of dissolved solids concentration, from 176 to 434 parts per million. The similarity of waters from the alluvium and from the upper member of the Cutler formation indicates the possibility that the water in the alluvium originates as seepage from the upper member of the Cutler formation.

Water from the lower member of the Cutler formation (analyses BP-6 and BP-11) appears to be similar in chemical character to water from the upper member. However, water from the lower member has a somewhat lower chloride-sulfate ratio than water from the upper member, even though both these anions constitute a comparatively minor part of the dissolved solids in the water from both members. The first of the two samples from spring BP-10 shows the quality of water from the upper member, and the second of these samples shows the resulting change in chemical character when water from the upper member is mixed with water from the lower member of the formation.

Water from the agglomerate in Buell Park contains moderate amounts of dissolved solids but is distinctly different in chemical character from the waters of the sedimentary rocks. A rather large proportion of the dissolved matter consists of silica, which is not unusual in water from igneous rocks. More than 10 percent of the dissolved matter in water from spring BP-1 is silica. The principal cation in water from the agglomerate is magnesium and the principal anion bicarbonate, but the water from spring BP-3 contains larger amounts of sodium and sulfate than water from spring BP-1. The magnesium in these waters probably comes from decomposition of olivine which is a common mineral in the agglomerate.

The chemical character of water from spring BP-2 closely resembles that of water from the agglomerate.

Quality of water in relation to use

Although all the waters analyzed are hard, they may be considered of good quality for domestic use on the basis of dissolved solids content. None of the waters contain excessive concentrations of fluoride.

Water from the agglomerate in Buell Park probably would be less desirable for boiler use than water of comparable hardness from the alluvium in the Sawmill area because of the higher concentrations of silica in the Buell Park water. Silica is deposited as a component of boiler scale.

POSSIBILITIES OF DEVELOPING ADDITIONAL WATER SUPPLIES

Buell Park

Assuming that the minimum amount of water available from the three springs in Buell Park (BP-1, 2, 3) is 80 percent of the lowest measured discharge, the total amount that could be produced from all three springs would be about 200 gallons per minute, and the total amount that could be produced from springs BP-1 and BP-2 would be about 125 gallons per minute. On the basis of a daily rate of consumption of 150 gallons per capita, all three springs would support a population of 1,920, and springs BP-1 and BP-2 would support a population of 1,200.

Plate 1 shows that spring BP-3 is at the eastern edge of Buell Park near the only drainage outlet. If a community is constructed within the park, some provision must be made for disposal of sewage wastes. If these wastes are dissipated within the park, the flow of spring BP-3 may eventually become contaminated. If the wastes are carried by pipe line down the outlet canyon below the spring, there is little danger of contamination. A possible alternative would be to develop springs BP-1 and BP-2 for a domestic supply and to develop spring BP-3 as a power plant and garden supply.

If the school is built near Fort Defiance as originally planned, the water supply in Buell Park could be collected into a pipe line and would flow by gravity to the school site. About 14 miles of pipe line would be required.

Sawmill area

As a result of the investigation by the Geological Survey the present writers concur in Rupkey's[12/] recommendation that Morgan Spring (BP-6) be developed as a supplemental water supply for the Tribal Sawmill. The anticipated water demand after expansion of the mill and community has been estimated to be 180,000 gallons per day. The existing supplies are capable of producing a minimum of about 50,000 gallons per day. The estimated potential of Morgan Spring is 144,000 gallons per day, which gives a margin of 14,000 gallons per day more than the anticipated demand.

The altitude of the water surface at Morgan Spring is 225 feet lower than the top of the Sawmill storage tank. The distance is 2½ miles.

12/ Rupkey, R. H., op. cit., pp. 8-11.

In the event that the water demand after expansion exceeds 180,000 gallons per day, it might be advisable to construct part of the community housing facilities in Buell Park, where a water supply can be developed.

CONCLUSIONS AND RECOMMENDATIONS

1. About 270,000 gallons of water per day will be needed to supply a proposed school to be built either near Fort Defiance or in Buell Park.

2. It is concluded that three springs in Buell Park can be developed to supply a minimum of 200 gallons per minute or 288,000 gallons per day, provided adequate precautions are taken to prevent contamination of one of the springs by sewage wastes. Water from these springs is considered suitable for domestic use, although hard. The water supply is considered adequate to warrant construction of the proposed school.

3. About 180,000 gallons of water per day will be needed at the Navajo Tribal Sawmill after the mill and community are enlarged. The existing water supply will yield a minimum of about 50,000 gallons per day.

4. It is concluded that a spring 2½ miles south of the Sawmill could be developed to supply a minimum of 100 gallons per minute or 144,000 gallons per day. The pump lift from this spring to the existing tank at the Sawmill would be about 225 feet. Water from this spring is considered suitable for domestic use. Although hard, this water is slightly softer than the water now being used. The supply obtainable from this spring is considered adequate to warrant proceeding with the planned expansion program at the Sawmill.

Table 1.-Records of wells and springs in Buell Park-Sawmill area, Apache County, Ariz.

(All wells are dug unless otherwise noted in "Remarks" column.)

Well or spring no.	Location (miles from Tribal Sawmill)	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
c/BP-1	3.9 E.	Navajo Service	-	-	7,152	-	-
c/BP-2	3 E.	do.	-	-	7,175	-	-
c/BP-3	4.4 E.	do.	-	-	7,083	-	-
c/BP-4	.4 SE	Tribal Sawmill	-	-	7,534	13	240
c/BP-5	.5 W	Navajo Service	-	-	7,628	20	120
c/BP-6	2.7 S	do.	-	-	7,444	-	-
c/BP-7	.8 N	do.	-	-	7,735±	-	-
BP-8	.1 NW	do.	-	-	7,601±	13	120

a/ N, none; C, cylinder; G, gasoline; number indicates horsepower.
b/ D, domestic; S, stock; I, irrigation; Ind., industrial; P, public supply; N, not used.
c/ See table 3 for analysis of water sample.

Records obtained by L. C. Halpenny, H. A. Whitcomb, and S. F. Turner

Well or spring no.	Water level: Depth below measuring point (feet)	Water level: Date of measurement	Pump and power a/	Use of water b/	Temp. °F.	Remarks
BP-1	Flows	-	N	D,S	54	Spring in Buell Park. Issues from agglomerate at base of hill near center of valley. Measured discharge: 17 gallons per minute on Oct. 3, 1948; 20 gallons per minute on Apr. 14, 1949; 17 gallons per minute on June 5, 1949.
BP-2	do.	-	N	D,S,I	54	Spring in Buell Park. Issues from agglomerate in bed of Peridot Creek. Measured discharge: 140 gallons per minute on Oct. 3, 1948; 178 gallons per minute on Apr. 13, 1949; 192 gallons per minute on June 5, 1949.
BP-3	do.	-	N	D,S,I	53	Spring in Buell Park. Issues from agglomerate in bed of wash tributary to Peridot Creek. Measured discharge: 90 gallons per minute on Oct. 3, 1948; 110 gallons per minute on Apr. 14, 1949; 99 gallons per minute on June 5, 1949.
BP-4	4.35	Oct. 25, 1948	C,G, 20	Ind.	52	Supplies log pond and mill at Tribal Sawmill. Dug pit; intercepts surface flow and underflow of principal wash at Sawmill. The supply is partially sustained by infiltration from log pond at mill upstream. Measured discharge: 62 gallons per minute on Apr. 15, 1949.
BP-5	5.50	do.	C,G, 3	P	62	School well; supplies entire community at Sawmill. Dug rock-lined caisson at edge of wash. Measured drawdown: 4.90 feet, pumping 29 gallons per minute on Apr. 18, 1949.
BP-6	Flows	-	N	D,S	50	Morgan Spring. Issues from lower member of Cutler formation in bed of wash. Measured discharge: 168 gallons per minute on Apr. 14, 1949.
BP-7	do.	-	N	D,S	43	"Oil Seep" Spring. Issues from upper member of Cutler formation in bed of wash. Estimated discharge: 3 gallons per minute on Oct. 25, 1948. Measured discharge: 22½ gallons per minute on Apr. 14, 1949.
BP-8	0.30	Mar. 30, 1949	N	N	-	Former water supply for mill at Sawmill; now abandoned. Measured drawdown: 13.4 feet, pumping 4 gallons per minute on Mar. 30, 1949. Bottom of well is at upper surface of lower member of Cutler formation; obtains water from alluvium.

Table 1.-Records of wells and springs in Buell Park-Sawmill area, Apache County, Ariz.-Cont.
(All wells are dug unless otherwise noted in "Remarks" column.)

Well or spring no.	Location (miles from Tribal Sawmill)	Owner	Driller	Date completed	Altitude above sea level (feet)	Depth of well (feet)	Diameter of well (in.)
BP-9	.2 NW	Navajo Service	-	-	7,607±	12	72
c/BP-10	2.2 NE	do.	-	-	7,450±	-	-
c/BP-11	4.1 SE	do.	-	-	7,250±	-	-
18K-306	0	do.	Burt Cravath	1942	7,598±	845	12½

a/ N, none; C, cylinder; G, gasoline; number indicates horsepower.
b/ D, domestic; S, stock; I, irrigation; Ind., industrial; P, public supply; N, not used.
c/ See table 3 for analysis of water sample.

Records obtained by L. C. Halpenny, H. A. Whitcomb, and S. F. Turner

Well or spring no.	Water level: Depth below measuring point (feet)	Water level: Date of measurement	Pump and power a/	Use of water b/	Temp. °F.	Remarks
BP-9	-	-	C,W	N	-	Former domestic supply for residents of Sawmill community; now abandoned. Obtained water from alluvium.
BP-10	Flows	-	N	N	58	Spring in Buell Park. Seeps from both members of Cutler formation for 4½ miles along upper Peridot Creek. Flow is seasonal: on Dec. 8, 1948, the estimated discharge was 20 gallons per minute; on Apr. 16, 1949, the measured discharge was 178 gallons per minute.
BP-11	do.	-	N	D,S	48	Spring in Buell Park. Issues from top of lower member of Cutler formation. Estimated discharge: 10 gallons per minute on Dec. 8, 1948; 20 gallons per minute on Apr. 16, 1949.
18K-306	3.00	Mar. 30, 1949	N	N	-	Drilled well. Did not produce water from Cutler formation; was perforated opposite alluvium and is reported to have yielded 30 gallons per minute. Now abandoned. See log, table 2.

Table 2.-Driller's log of well 18K-306, at Navajo Tribal Sawmill, Apache County, Ariz.

	Thickness (feet)	Depth (feet)
Alluvial fill - - - - -	15	15
Light-red sandstone - -	7	22
Light-red sandy shale -	17	39
Light-red sandstone - -	4	43
Red shale - - - - - - - -	19	62
Very hard reddish-brown sandstone - - - - - -	702	764
Light-gray sandstone -	5	769
Reddish-brown sandstone	15	784
Very hard gray sandstone	14	798
Fine-grained quartzite	47	845
TOTAL DEPTH - - - - - -		845

Driller reported: "Hardest formations encountered in 25 years of drilling on Navajo Reservation". Probably encountered pre-Cambrian quartzite at 784 feet.

Table 3.-Analyses of water from wells and springs in Buell Park-Sawmill area, Apache County, Ariz.
Analyses by Geological Survey
(Numbers correspond to numbers on plate 1 and in table 1.)
(Parts per million except specific conductance.)

Well or Spring No.	Date of collection	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 $CaCO_3$
BP-1	Sept. 29, 1948	458	31	20	42	19	279	22	7	0.2	2.5	281	222
BP-2	do.	342	29	28	25	9.7	200	18	6	.2	2.8	217	173
BP-2a/	do.	619	34	25	50	42	337b/	62	11	.2	3.9	394	268
BP-3	do.	642	32	20	40	66	314c/	74	14	.2	4.8	406	214
BP-4	Oct. 25, 1948	552	15	67	22	23	306	24	21	.4	.7	324	258
BP-5	do.	514	-	-	-	-	312	-	11	-	-	-	-
BP-5	Apr. 18, 1949	511	-	75	13	21	313	13	12	-	.2	288	240
BP-6	Nov. 1, 1948	459	16	58	20	13	260	24	9	.2	4.2	272	226
BP-7	Oct. 25, 1948	733	-	106	17	41	430	29	29	-	.4	434	334
BP-10 d/	Apr. 16, 1949	309	-	46	7.3	12	168e/	18	10	.2	.2	176	145
BP-10f/	do.	410	-	58	17	9.0	252	17	7	0	0	232	214
BP-11	do.	491	-	64	24	10	298	22	9	.2	.1	276	258
- g/	Sept. 29, 1948	644	35	24	49	53	332h/	79	13	.2	3.7	420	262

a/ Collected 3/4 mile downstream.
b/ Includes 21 ppm carbonate (CO_3).
c/ Includes 10 ppm carbonate (CO_3).
d/ Near upper end of seepage area.
e/ Includes 7 ppm carbonate (CO_3).
f/ At lower end of seepage area.
g/ Combined flow of BP-2 and BP-3.
h/ Includes 23 ppm carbonate (CO_3).