GROUND WATER AT TOWAOC, COLORADO

By

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INTRODUCTION

At the request of the U. S. Bureau of Indian Affairs, the Ground Water Branch of the U. S. Geological Survey made a reconnaissance of ground-water conditions in part of the Southern Ute Indian Reservation in the vicinity of Towaoc School. The study was requested because the water supply for the school and settlement was inadequate.

Location

The area described in this report comprises about 27 square miles and lies in the northeastern part of the Southern Ute Indian Reservation, which is in the southern part of Montezuma County, Colorado. The community of Towaoc is about 10 miles southwest of Cortez and is 2 miles west of U.S. Highway 666 and lies at an altitude of about 5,900 feet. The community consists of a boarding school, trading post, steam plant, three dormitories, a hospital, and staff houses. The boarding school had been closed for many years because of an inadequate water supply but was reopened in the fall of 1953. The population of the community during the school season is about 200.

Topography and Drainage

The Towaoc area is characterized by steep to moderate slopes. West of Towaoc, along the flank of the Ute Mountain intrusives, the area is dissected by deep canyons; east of Towaoc the slopes are relatively smooth. The area is drained by Cottonwood Creek and Navajo Wash, both of which drain southward toward the Mancos River.

Summary of Problem

Water for Towaoc has been obtained from an infiltration gallery about 1.5 miles northwest of the community (plate 1). The quantity of water reported to be discharged by the gallery varies from about 35 gallons per minute for a short period during the spring runoff to about 4.1 gallons per minute during the fall and winter. Officials of the Indian Service have proposed a housing program for the Towaoc area that will require a larger and more permanent water supply than can be supplied by the infiltration gallery. They estimate that the quantity of water required will be about 46,000 gallons per day or about 32 gallons per minute.

An attempt was made in 1931 to increase the water supply by drilling a well to a depth of 1,750 feet, but it apparently failed because of improper well construction. Attempts made recently to increase substantially the quantity of water produced by the gallery have also failed.

Field Work and Acknowledgments

Records of three wells and one spring in the Towaoc area were obtained during this study, and their locations are shown on plate 1. Several pumping tests were run on well 5 in oreder to determine the permeability of the shallow aquifer. A reconnaissance of the geology of the Towaoc area was made by the writer in order to determine the areas of recharge and the related structural features of the deep-lying aquifers.

Joseph T. Callahan began the field work in December 1953 and continued until mid-January after which the field work was continued by the writer. Records of three wells and one spring in the Towaoc area were obtained during this study and 4 test holes were drilled. The locations of the wells, spring, and test holes are shown on plate 1. The test holes and

wells are numbered consecutively, the wells being shown on plate 1 by open circles and the test holes by solid circles. Several pumping tests were run on well 5 in order to determine the permeability of the shallow aquifer. Well cuttings from all the shallow test holes and from the first 472 feet of test hole 6 were collected and studied in the field (test hole 6 had not been completed at the time of this report). The results of the test drilling are listed at the end of this report and the locations of the test holes are shown on plate 1. A reconnaissance of the geology of the Towaoc area was made by the writer in order to determine the areas of recharge and the related structural features of the deep-lying aquifers.

Officials of the Indian Service had previously collected 12 samples of water for analysis and the writer collected 7 samples during this investigation. The results of the water analyses are given in table 2. Olin J. McClerry, irrigation engineer for the Indian Service, determined the altitudes of most of the test holes and wells in the area.

In addition to the data obtained as a part of this investigation, the writer had access to considerable published and unpublished geologic and hydrologic data on this and adjacent areas. These included unpublished data on the geology and ground-water resources of the Navajo Reservation, compiled by the Holbrook, Arizona, office of the Ground Water Branch, U. S. Geological Survey, and unpublished geologic data on the Ute Mountain area compiled by the Mineral Deposits Branch of the Geological Survey.

GEOLOGY AND GROUND-WATER RESOURCES

As no detailed geologic field work was done during this investigation, the following discussion of the geology in the vicinity of Towaoc is generalized and is intended only as a background for the description of the ground-water possibilities of the area.

Sedimentary Rocks and their Water-Bearing Properties

The section of rocks that are believed to underlie the Towaoc area downward to the Navajo sandstone is as follows:

QUATERNARY
- Alluvium

CRETACEOUS
- Mancos shale
- Greenhorn limestone equivalent
- Dakota sandstone
- Burro Canyon formation

JURASSIC
- Morrison formation
  - Brushy Basin shale member
  - Salt Wash sandstone member

JURASSIC--Continued
- San Rafael group
  - Summerville formation(?)
  - Bluff sandstone
  - Entrada sandstone
    - Slick Rim member (of local usage)
  - Carmel formation
- Glen Canyon group
  - Navajo sandstone

Jurassic Rocks

The oldest rocks in the area that are considered to be potential aquifers are of late Jurassic age. They do not crop out in the vicinity of Towaoc but are exposed and were examined in McElmo Canyon northwest of Towaoc. Older rocks were not considered potential aquifers because they lie at too great a depth at Towaoc.

Glen Canyon Group.--The Glen Canyon group includes the Navajo sandstone, which does not crop out in the area of this report. The Navajo is reported to have been encountered in well 7 at a depth of about 1,190 feet, but its character at Towaoc is not known owing to the inadequacy of the log.

The Navajo sandstone exposed in McElmo Canyon is massive, cross bedded, fine grained, and is pink, white, orange, yellow, and in part mottled. The grains of quartz are clear and are cemented with lime. The Navajo is a moderately good aquifer in many areas and commonly may yield as much as 25 gallons per minute to a properly constructed well. Upon completion of well 7, it was pumped for 48 hours at a reported rate ranging from 16.7 to 18.7 gallons per minute.

San Rafael Group.--The San Rafael group in the vicinity of Towaoc includes, in ascending order, the Carmel formation, the Entrada sandstone, the Summerville formation, and the Bluff sandstone. The rocks of this group do not crop out in the Towaoc area but are exposed in McElmo Canyon. They consist of claystones and poorly sorted sandstones and are not considered to be good aquifers. The log of well 7 indicates that 2.7 gallons of water per minute was obtained by means of a bailing test at a depth of about 865 feet from rocks that probably are a part of the San Rafael group.

Morrison formation.--The Morrison formation is believed to be represented in the vicinity of Towaoc by two members that are, in ascending order, the Salt Wash sandstone member and the Brushy Basin shale member. The Brushy Basin member is relatively impervious and will not yield water to wells. The Salt Wash sandstone member consists of fine- to medium-grained sandstone alternating with thin layers of claystone. A well near Aneth, Utah, is reported to have obtained 22 gallons of water per minute with a drawdown of 75 feet from the Salt Wash, but the driller of well 7 at Towaoc, Mr. W. L. Pierson, indicated that in well 7 the entire Morrison formation was very hard and tight and only small quantities of water were encountered.

Burro Canyon Formation.--The Burro Canyon formation is the lowermost of the Cretaceous rocks in the area. It was encountered at Towaoc at a depth of about 346 feet in test hole 6 and at about 283 feet in well 7. Diagrammatic sections of test hole 6 and well 7 are shown in figure 1. The Burro Canyon formation consists of beds of well sorted to poorly sorted fine- to medium-grained pebbly sandstone interbedded with silty to sandy shale. In some areas the Burro Canyon yields moderate quantities of water to wells, but a bailing test of test hole 6 indicated that a well in the Burro Canyon at Towaoc will yield about 2 to 3 gallons per minute with a drawdown of about 50 feet.

Dakota Sandstone.--The Dakota sandstone consists of very fine- to fine-grained hard sandstone with occasional thin layers of silty to sandy shale and a few lenses of coal or bituminous material. The Dakota crops out along the east flank of the Ute Mountains and dips steeply eastward toward Towaoc. It was encountered at a depth of 273 feet in test hole 6 and at a depth of about 230 feet in well 7. (See fig. 1.) The thickness of the Dakota at Towaoc is about 60 to 75 feet.

The Dakota sandstone is a moderately good aquifer in many areas, but in the vicinity of Towaoc it is very fine grained and firmly cemented and will yield very little water to wells. The first sandstone in the Dakota that contains water was encountered in test hole 6 at a depth of 320 feet. After the hole had been deepened to 335 feet, the water rose to within 81 feet of the ground surface after a period of 20 hours. A bailing test indicated that the sandstone will yield about 1.5 gallons per minute with a drawdown of about 65 feet.

Mancos Shale.--The Mancos shale lies conformably upon the Dakota sandstone. Its contact with the Dakota is easily observed owing to the sharp contrast between the dark shale of the Mancos with the underlying gray sandstone of the

Dakota. The Mancos shale is more than 1,000 feet thick in southwestern Colorado but only the lowermost part underlies the Towaoc area. It was 192 feet thick at test hole 6 and was reported to be about 155 feet thick in well 7. The Mancos contains two distinctive limestone intervals in the vicinity of Towaoc that can be recognized easily from drill cuttings and that can be correlated with similar rock units in other areas. The lowermost limestone consists of several thin beds of cream-colored chalky limestone having a total thickness of several feet. The interval is equivalent to at least part of the Greenhorn limestone of eastern Colorado and adjacent areas. It lies about 40 feet above the base of the Mancos shale at Towaoc and was encountered at a depth of 234 feet in test hole 6 and 180 feet in well 7. (See fig. 1.)

The upper limestone is hard, dark, finely crystalline, highly fossiliferous, and emits a strong petroliferous odor when broken. It is equivalent to the capping limestone of the Codell sandstone member of the Carlile shale in eastern Colorado. It crops out in a road cut a short distance east of the Pyle Trading Post but was not encountered in test hole 6 or well 7, indicating that it lies at least 300 and perhaps 500 feet above the base of the Mancos shale.

The Mancos shale is not considered to be water bearing although small quantities of water can be obtained from the Greenhorn limestone equivalent. A bailing test of test hole 6 indicated that it will yield about 3.5 gallons per minute with a drawdown of more than 50 feet.

Quaternary Deposits

Alluvium of Recent age underlies most of the area around Towaoc and consists of a mixture of clay, sand, and gravel. The finer materials were derived from the surrounding Cretaceous rocks whereas coarser materials consist mostly of fragments of igneous rocks derived from the Ute Mountain intrusives. The alluvium reaches its maximum thickness in buried channels that have been cut in the Mancos

shale by ancient streams and that may or may not conform with the present drainage. Test drilling is necessary, therefore, to locate the trough of the buried channels and, hence, the thickest and coarsest water-bearing materials. The thickness of the alluvium at Towaoc ranged from 21 feet in test hole 4 to 65 feet in well 7 and may locally be as much as 75 feet. Water moves relatively freely through the unconsolidated materials in the alluvium and supplies wells 5 and 8 as well as Navajo Spring.

WATER SUPPLIES

The study made at Towaoc included an investigation of the infiltration gallery, of all wells, and of Navajo Spring. The investigation indicated that only the alluvium and possibly the Navajo sandstone will yield sufficient water to supply the community of Towaoc. The data pertaining to the water supply of the area are given in the following sections.

Infiltration Gallery

The infiltration gallery north of Towaoc (pl. 1) along Cottonwood Creek has been the only source of water since the reopening of the Towaoc school in the fall of 1953. A layout of the gallery is shown in figure 2. The gallery consists of 12- to 24-inch perforated galvanized pipe placed on top of the Mancos shale and covered with 7 to 17 feet of sand and gravel. The diameter of the pipe used in various sections of the gallery are designated in figure 2. Segments AB and AC were constructed in January and February 1954 in an attempt to intercept water that was thought to be passing the older section of the gallery, but only a small quantity of additional water was captured. Water from the gallery is collected at the intake house where it is then conducted through $1\frac{1}{4}$ miles of 4-inch pipe to the Towaoc Reservoir. The reservoir is reported to be about 130 feet in diameter, 12 feet deep, and to have a storage capacity of about 1,000,000 gallons.

The discharge from the gallery ranged from 4.1 to 6.5 gallons per minute during the course of this investigation. The discharge is reported to be about 35 gallons per minute for a short period during the spring runoff, but it declines rapidly thereafter and is not sufficient to supply the community during

much of the year. The depth of water in Towaoc Reservoir was dropping at the rate of 1 inch per day in January and early February of 1954, and by February 15 a supply adequate for only about one week of use remained.

Well 7

Well 7 was drilled in 1931 by W. L. Pierson to a depth of 1,750 feet. The well is reported to have been cased with 8½-inch iron pipe to a depth of 420 feet and with 6 5/8-inch pipe to a depth of 1,073 feet; the remainder of the hole was not cased. The well was equipped with a 4-inch turbine pump powered by an electric motor. Information on the discharge and drawdown of the well, the length of time the well was in operation, and the reasons for abandoning the well are not available. As a result of an attempt to clean the well in the fall of 1953 it was found that the water from the Navajo sandstone may be locally contaminated with highly mineralized water from other aquifers not properly sealed off. The contamination apparently was caused in part by breaks in the casing resulting from corrosion. The depth to water level in well 7 was reported to be about 20 feet in 1931 whereas it was 60.83 feet on February 9, 1954, indicating further that the well is no longer properly cased and that water may be moving from one aquifer to another.

Six samples of water were collected by personnel of the Indian Service from various depths in well 7, and the analyses are given in table 2.

Well 8

Well 8, which supplies water to the Pyle Trading Post, is a 6-inch well having a reported depth of 98 feet. The well is equipped with a jet pump having a capacity of 10 gallons per minute and powered by a 1-horsepower electric motor. The pump forces water from the well to an elevated tank having a capacity

of about 150 gallons. Water from the tank can move by gravity through a ½-inch pipe to outlets at the trading post.

The depth to water level in well 8 was 33.60 feet below land surface on February 7, 1954. A pumping test run by Olin J. McClerry in November 1953 indicated that the well will yield about 3 gallons per minute with a drawdown of about 40 feet. One water sample was collected from the well and the analysis is given in table 2.

Well 5

Well 5 was drilled in February 1954 as a part of this investigation. Data pertaining to the construction, and performance of the well are given in figure 3.

The coefficient of transmissibility of the alluvium at well 5 was determined by a pumping test. On February 7, the well was pumped for 400 minutes at an average rate of 10.3 gallons per minute. Recovery of the water level was observed for 55 minutes after pumping stopped. The recovery formula of Theis[1/] which was used in computing the transmissibility at well 5, may be expressed as follows:

$$T = \frac{264\,Q}{s} \log_{10} \frac{t}{t'}$$

in which T = coefficient of transmissibility in gallons per day per foot

Q = pumping rate, in gallons a minute

t = time since pumping started, in minutes

t' = time since pumping stopped, in minutes

s = residual drawdown at the pumped well, in feet, at time t'

The residual drawdown (s) is computed by subtracting the static water-level measurement (table 1) from water-level measurements made after pumping stopped.

1/ U. S. Geol. Survey Water-Supply Paper 887, p. 95.

The proper ratio $\frac{\log_{10} t/t'}{s}$ is determined graphically by plotting $\log_{10} t/t'$ against corresponding values of s (fig. 4). This procedure is simplified by plotting t/t' on the logarithmic coordinate of semi-logarithmic paper, as shown in figure 4. The value of $\frac{\log_{10} t/t'}{s}$ is the slope of the straight line through the plotted points.

The discharge (Q) of well 5 was 10.3 gallons per minute. When values for $\frac{\log_{10} t/t'}{s}$, and Q are substituted in the Theis recovery formula, the coefficient of transmissibility of the alluvium near the pumped well is found to be about 4,800 gallons per day per foot. The average coefficient of permeability, which is equal to the coefficient of transmissibility divided by the thickness of saturated materials (12.9 feet), is about 370 gallons per day per square foot.

The water pumped from well 5 and the water obtained from the gallery have been the only sources of supply for the community since February 17, 1954. Graphs showing the pumping level in well 5 and the depth of water in the Towaoc Reservoir are shown in figure 5.

Navajo Spring

Navajo Spring discharges along the contact of the alluvium and the Mancos shale near Navajo Wash south of Towaoc (pl. 1). Water from the spring is collected in a concrete reservoir about 7 feet wide, 22 feet long, and 5 feet deep. Water from the reservoir is conducted through about 400 feet of 1-inch pipe to stock troughs. The water is used for domestic and stock purposes. The average discharge of the spring during this study was 4.3 gallons per minute.

Table 1.--Data on pumping test of well 5

Time since pumping started (minutes) t	Time since pumping stopped (minutes) t'	t/t'	Depth of water level (feet)	Residual drawdown (feet) (s)	Remarks
			31.07		Static water level
0					Pump started
400	0				Pump stopped
401	1	401	33.89	2.82	
402	2	201	32.74	1.67	
403	3	134.3	32.73	1.66	
405	5	81	32.58	1.51	
408	8	51	32.45	1.38	
410	10	41	32.42	1.35	
415	15	27.6	32.31	1.24	
427	27	15.8	32.17	1.10	
435	35	12.4	32.09	1.02	
443	43	10.3	32.04	.97	
455	55	8.3	31.94	.87	

QUALITY OF WATER

The analyses of nineteen samples of water in table 2 show the chemical character of ground and surface waters in the vicinity of Towaoc. The analyses show only the dissolved mineral content of the waters and do not indicate their sanitary condition.

The excessive hardness and high mineral content of the water from Navajo Wash indicate that water from this source is not suitable for domestic use. The analyses show that all the other surface waters, including springs, are hard but would be suitable for domestic use.

Hardness in ground water in the vicinity of Towaoc ranges from 309 parts per million in water from the Dakota sandstone and Burro Canyon formation to 447 parts in water from the alluvium (well 8). The concentration of dissolved solids in the ground water analyzed ranged from 510 parts per million in water from the alluvium to 946 parts in water from the Dakota and Burro Canyon formations. The bicarbonate content ranged from 286 parts per million in water from the alluvium to 692 parts in water believed to be from the Navajo sandstone. The presence of hydroxide in the sample collected from the Greenhorn limestone equivalent in test hole 6 indicates contamination from cementing operations and was not included in the preceding discussion. The sample had a very strong odor of hydrogen sulfide at the time of collection, however, and probably would be unsuitable for domestic use. The last analysis shown in table 1 represents a mixture of waters from the Dakota sandstone and the Burro Canyon formation. Water from these aquifers is not satisfactory for domestic use because of the high concentration of dissolved solids and the strong odor of hydrogen sulfide.

The analyses of water from well 7 do not represent water from the Navajo sandstone but, as a result of improper well construction, represent a mixture of waters from several aquifers. Water from the alluvium (well 5) is satisfactory for domestic use and is of the best quality of those sampled in the area.

METHODS OF OBTAINING ADDITIONAL SUPPLIES OF SUITABLE WATER

Wells in Alluvium

No data were available prior to this investigation concerning the water levels, yield, or performance of wells in the alluvium at Towaoc. Pumping tests on well 5 and daily observation of pumping levels have shown that additional supplies can be developed from shallow wells tapping the alluvium in this area. It is emphasized, however, that systematic test drilling should precede any planned well development in the area in order to determine the location and extent of the buried channel in the vicinities of wells 5 and 8 and to determine the thickness and character of the water-bearing materials in the buried channel. The locations of two proposed lines of test holes are shown on plate 1. It is believed that a well can be developed along line A or line B that will have a discharge comparable to that of well 5.

Well in Bedrock

Data obtained on the drilling and repairing of well 7 indicate that a properly constructed well drilled into the Navajo sandstone at Towaoc probably would yield sufficient water to supply most if not all the present requirements of Towaoc. The casing in well 7 is reported to be broken or corroded to the extent that highly mineralized or otherwise undesirable waters from a few aquifers mix freely with waters of good quality from other aquifers with the result that all the water becomes unsuitable for most uses. If test hole 6 is deepened to the Navajo sandstone, care should be taken that the Dakota sandstone and the Greenhorn limestone equivalent and any other aquifers containing undesirable water are properly sealed off with casing and with cement to prevent entry of undesirable water into the well. It probably would also be desirable to plug

well 7 in order to prevent additional contamination of the aquifers. It is likely that test hole 6, if deepened, will encounter the top of the Navajo at a depth of about 1,250 feet.

CONCLUSIONS

The following conclusions and recommendations are made for the development of a water supply for the Towaoc community.

1. The water supply at Towaoc is derived from an infiltration gallery and well 5. The infiltration gallery supplies about 5,800 gallons of water per day and the well supplies about 17,300 gallons per day. About 23,000 gallons per day of additional potable water will be needed to insure an adequate supply for the area.

2. The required amount of water for the area probably can be obtained by drilling one or two additional wells in the alluvium. Systematic test drilling is the most reliable method of locating an additional well or wells and, based on available information, lines A and B (pl. 1) are the most promising areas in which to find the thickest section of water-bearing materials.

3. Test hole 6 could be deepened into the Navajo sandstone in an attempt to furnish the required amount of water for the community but the cost probably would be much greater than if an attempt was made to develop additional water from the alluvium.

4. A careful study of the cuttings from test hole 6 indicates that the sandstones in the Dakota and Burro Canyon formations are more firmly cemented and less porous than they generally are elsewhere indicating that the rocks have been materially affected in this area by intrusion and uplift of the Ute Mountains. Drilling records of well 7 indicate also that the Salt Wash sandstone member of the Morrison formation is less productive of water at Towaoc than elsewhere. It is logical to assume, therefore, that the porosity of the deeper lying aquifers at Towaoc may have been similarly reduced. It does not appear feasible to attempt to tap the deeper lying aquifers unless adequate supplies of water cannot be obtained from the alluvium after it has been thoroughly prospected.

LOGS OF TEST HOLES AND WELLS

Driller's log of test hole 1, drilled by Jack H. Wesch, 1953. Surface altitude, 5,884.4 feet.

	Thickness (feet)	Depth (feet)
Alluvium		
Soil	3	3
Boulders and coarse gravel	17	20
Gravel, fine, interbedded with yellow clay	15	35
Clay, yellow, interbedded with some fine gravel	5	40
Mancos shale		
Shale, blue	12	52

Driller's log of test hole 2, drilled by Jack H. Wesch, 1953. Surface altitude, 6,380.1 feet.

Alluvium		
Soil, red	4	4
Soil, gravelly, red	12	16
Gravel, fine, red	4	20
Gravel, fine, buff (contains some water)	13	33
Mancos shale		
Shale, dark-blue	2	35

Driller's log of test hole 3, drilled by Jack H. Wesch, 1953. Surface altitude, 6,370.5 feet.

Alluvium		
Soil	2	2
Gravel	1	3
Boulders	5	8
Gravel	23	31
Mancos shale		
Shale	19	50

Driller's log of test hole 4, drilled by Jack H. Wesch, 1953.

Alluvium		
Boulders	3	3
Boulders and gravel	3	6
Clay, yellow, interbedded with gravel	3	9
Gravel (contains some water)	12	21
Mancos shale		
Shale, blue	6	27

Sample log of well 5, drilled by Jack H. Wesch, 1954. Surface altitude, 5,884.4 feet.

	Thickness (feet)	Depth (feet)
Alluvium		
Clay, silty to sandy, very fine, brown, containing fine to very coarse gravel	9	9
Sand, very fine to very coarse, containing very fine to very coarse gravel; interbedded with soft yellow clay	23	32
Sand and gravel; very fine to very coarse, containing a few large boulders (contains water)	12	44
Mancos shale		
Shale, blocky, silty, dark-blue	21.8	65.8

Sample log of test hole 6, drilled by Jack H. Wesch, 1954. Surface altitude, 5,888.6 feet.

Alluvium		
Clay, silty to sandy, containing some fine to very coarse gravel; brown	24	24
Clay, silty to sandy, yellow, containing fine to coarse gravel	3	27
Sand and gravel; fine to coarse; containing silty to sandy clay	13	40
Sand, very fine to very coarse, containing fine to medium gravel and some silty clay	2	42
Mancos shale		
Shale, silty, blocky, dark-blue	139	181
Clay, bentonitic, light-gray	4	185
Shale, silty, blocky, dark-blue, containing thin layers of very fine sand	16	201
Shale, silty, dark-gray, interbedded with thin layers of dark-blue shale	9	210
Shale, silty, blocky, dark-blue	13	223
Shale, silty, blocky, interbedded with thin layers of limestone	11	234
Limestone, dense, hard, badly broken, light- to dark-gray (Greenhorn limestone equivalent, contains water.)	3	237
Shale, silty to slightly sandy, hard	4	241
Shale, silty, blocky, interbedded with thin layers of bentonite	4	245
Shale, silty to slightly sandy, dark bluish-gray	13	258
Shale, silty to slightly sandy, bluish-gray, interbedded with thin layers of bentonite	4	262
Shale, silty to very sandy, very fine, bluish-gray	11	273
Dakota sandstone		
Sandstone, very fine to fine, hard, well cemented, slightly clayey, gray, containing a few thin layers of sandy shale	16	289
Shale, silty to sandy, very fine, firm to soft, interbedded with layers of very fine sand; bluish-gray	5	294
Sandstone, very fine, interbedded with layers of sandy shale; dark-gray	5	299

Sample log of test hole 6--Continued

	Thickness (feet)	Depth (feet)
Dakota sandstone--Continued		
Sandstone, very fine to medium, hard, firmly cemented, dark-gray	4	303
Sandstone, silty to very fine, hard, dark-gray, containing thin layers of dark-brown to bluish-black shale	4	307
Sandstone, silty to very fine, hard, light-gray, containing a few rounded fragments of ironstone and thin layers of brown carbonaceous clay (contains a little water at 320 feet)	26	333
Sandstone, very fine, containing well rounded grains interbedded with thin layers of sandy carbonaceous shale	4	337
Sandstone, silty to fine, gray, containing thin layers of dark-gray to brown carbonaceous shale (Water has strong sulfur odor)	6	343
Coal, soft, black	3	346
Burro Canyon formation(?)		
Sandstone, silty to very fine, gray, containing thin layers of dark-gray to brown carbonaceous shale	5	351
Shale, firm, silty to slightly sandy, blocky, dark-gray	4	355
Sandstone, silty to very fine, hard, firmly cemented, interbedded with thin layers of blue shale	3	358
Shale, silty to sandy, hard, dark-gray, interbedded with thin layers of silty to very fine-grained light-gray sandstone	24	382
Shale, silty to slightly sandy, firm to soft, dark-blue	8	390
Shale, silty to sandy, firm, carbonaceous, brown to black	4	394
Sandstone and shale, silty to very fine	7	401
Shale, silty to sandy, firm, dark bluish-gray, interbedded with thin layers of carbonaceous shale	7	408
Sandstone, silty to very fine, hard, light-gray to tan, containing a few fragments of dark-brown silty shale	10	418
Shale, silty to sandy, firm, carbonaceous, dark-gray to black	7	425
Sandstone, very fine to fine, light-gray to tan (Water has strong sulfur odor)	6	431
Sandstone, silty to fine, soft, light-tan, containing some very fine gravel and a few rounded fragments of brown silty clay	16	447
Sandstone, silty to fine, soft, containing some medium-grained sand and very fine gravel; poorly sorted; light-tan	5	452
Sandstone, very fine to fine, well sorted, containing some very fine light-tan gravel	6	458
Sandstone, very fine to fine, containing some medium-grained light-gray to tan sand	13	471
Morrison formation		
Brushy Basin shale member		
Sandstone, silty to fine, hard, containing some blue and greenish-blue shale and abundant pyrite	1	472
Shale, silty to slightly sandy, bluish-green	..	472

Driller's log of well 7, drilled by W. L. Pierson, 1931. Surface altitude, 5,922.7 feet.

	Thickness (feet)	Depth (feet)
Alluvium		
Sedimentary dirt, brown	9	9
Shale or sedimentary mud; brown	18	27
Sediment, brown	18	45
Granite boulders and gravel (contains water)	3	48
Sediment, black	12	60
Boulders and gravel (contains water)	5	65
Mancos shale		
Shale, dark	25	90
Shale	88	178
Shell (Greenhorn limestone equivalent)	2	180
Broken formation (Greenhorn limestone equivalent, contains water)	2	182
Shale	38	220
Dakota sandstone		
Sand	10	230
Shale	5	235
Sand	30	265
Shale	5	270
Sand (Driller's note: All of this sand is hard and most of it probably is dry.)	10	280
Coal	3	283
Burro Canyon formation(?)		
Sand (Driller's note: All of this sand is hard and most of it probably is dry.)	7	290
Sand	50	340
Shale, sandy	25	365
Sand	45	410
Morrison, Summerville, Entrada, and Carmel formations, undifferentiated		
Sand and shale, green	10	420
Shale, green and lime shells, gray	50	470
Shale, gray and green, containing hard lime shells	45	515
Shale, gray and green, containing hard lime shells (Driller's note: Unit is about 50 percent lime.)	35	550
Shale, green and gray, alternating with shells of hard lime	120	670
Shale, sandy, gray and green (Contains water. Bail test indicates about 1 gpm.)	5	675
Shale, gray and green	35	710
Sand, gray (Driller's note: Some water between 735 and 750; about 50 percent increase.)	45	755
Shale, green, interbedded with layers of gray sand (Contains water. Bail test indicates about 2.7 gpm.)	110	865
Shale and sand; pink	325	1,190
Navajo sandstone(?)		
Sand, pink (contains water)	60	1,250
Shale, pink	15	1,265
Shale, sandy, pink (Driller's note: Water level raised 75 feet at 1,610 feet, but no appreciable sand was found at this depth. Well was pumped continuously for 48 hours from January 14 to January 15 at a rate of between 16.7 and 18.7 gpm.)	485	1,750

DRILLING RECORD OF TEST HOLE 6

Driller: Jack H. Wesch

1954

February 13	-	Drilling started.
February 15	-	44.7 feet of 10-inch surface casing set in hole.
February 16	-	Hole caved badly between 59 and 110 feet.
February 19	-	Drilling from 150 to 231 feet.
February 20	-	Drilling from 231 to 246 feet. Hole contained about 50 feet of water from the Greenhorn limestone equivalent. Hole was bailed dry and the water level was then allowed to recover for about 1 hour before starting a bailing test. The bailing test indicated that about 3.5 gpm with a drawdown of more than 50 feet can be expected from this interval.
February 22	-	Water level 50.74 feet below ground surface.
February 24	-	Twelve sacks of cement were used to cement a 10-inch casing in place.
February 25	-	244.6 feet of 8 5/8-inch O.D. casing set to seal off water from Greenhorn limestone equivalent.
February 27	-	Water level 81.00 feet below ground surface (first water encountered in the Dakota). Depth of hole at this point was 335 feet. Well was bailed dry and the water level was allowed to recover for about 2 hours before starting a bailing test. The bailing test indicated that about 1.5 gpm with a drawdown of more than 66 feet can be obtained from the upper part of the Dakota sandstone.
March 1	-	Water level 68.50 feet below ground surface. Hole bottomed at 352 feet and cased to 244.6 feet.
March 2	-	Depth of hole 391 feet. Temperature of water 58°F.
March 8	-	Setting 8 5/8-inch casing at 389 feet to test water in the Burro Canyon formation.
March 9	-	Depth of hole at end of work day was 433 feet. Water encountered at 427 feet.
March 10	-	Water level 300.00 feet below ground surface. Water has strong sulfur odor. Depth of hole 477 feet. Bailing test indicates that 2.3 gpm with a drawdown of more than 53 feet can be obtained from the Burro Canyon formation.
March 15	-	Water level 83.00 feet below ground surface.

RECORD OF WELL 5

Owner: U. S. Bureau of Indian Affairs

Driller: Jack H. Wesch

Elevation at land surface: 5,884.4 feet

Depth of well: 65.8 feet

Principal waterbed: sand and gravel
Depth to principal waterbed: 32 feet; thickness of bed: 12 feet

Casings: type iron; size 8 5/8-inch O.D.; length 45.8 feet; between depths of 0 and 45.4 feet. Type iron; size 7-inch O.D.; length 21.8 feet; between depths of 44.0 and 65.8 feet.

Pump: Type jet; size or capacity 15 gallons per minute; kind of power electric (3 h.p.)

Yield: 13 gallons per minute

Quality of the water: suitable for domestic use; temperature of water: 55°F.

TABLE 2.—Analyses of spring and surface waters at Towaoc.

Analyzed by U. Geological Survey
Dissolved constituents given in parts per million.

No. on plate 1	Description	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	pH	Specific conductance, in 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 (sum)	Hardness (calculated as $CaCO_3$) Total	Hardness (calculated as $CaCO_3$) Non-carbonate	Sodium in percentage of total bases	Remarks
1	Seep in wash ½ mile southwest of Towaoc			7-11-50	72		1,060	19	78	42	114	330	296	20	0.2	0.4	737	367	98	40	
2	Seep in wash 2 miles upstream from Towaoc			7-11-50	50		939	21	162	26	13	360	227	10	.1	.4	638	519	224	5	
3	Tom Root Spring			10-3-51			833	18	155	16	12	395	151	4	.1	.1	586	452	137	5	
4	Navajo Spring			10-3-51	61.5		1,050	27	141	39	39	224	372	18	.3	.6	747	512	329	14	
5	Navajo Wash			3-1-53			7,870				1,100	908 1/		166				2,530		60	
6	8	98	Alluvium	11-5-53			971	20	100	48	21	302	223	8	.2	1.2	570	447	200	9	
7	7	1,750	Navajo sandstone (?)	11-10-53			1,310					782 2/		5							Water level 55 feet. Water is black.
8	Do.	1,750	do	do			1,290					736 3/		5							Water level 160 feet. Water is black.
9	Do.	1,750	do	do			1,340					699		5							Water level 369 feet. Water is black.
10	Do.	1,750	do	do			1,300					752 4/		8							Water level 508 feet. Water is black.
11	Do.	1,750	do	do			1,300					795 5/		9							Water level 650 feet. Water is black.
12	Do.	1,750	do	do			1,390					844 6/		5							Water level 900 feet. Water is black.
13	5	65.8	Alluvium	2-7-54	56	8.5	758				17	286	161	8	.2		527	376	142	9	Sample collected after pumping 6 minutes, at 129 gpm
14	Do.	65.8	do	2-7-54	56	7	765				17	290	158	8	.2		530	376	138	9	Sample collected after pumping 6 hours, at 129 gpm
15	Do.	65.8	do	3-12-54	58		781	22	122	20	21	292	169	10	.2	2.3	510	386	147	11	Sample collected after 25 days of continuous pumping; pressure of 596 pf of hydrazine indicates contamination from cementing.
16	6	246	Greenhorn limestone equivalent	2-22-54	58	11.7	8,900					197									Water level 61 feet.
17	Do.	330	Dakota sandstone	2-27-54	54	8.5	1,440					512 7/		23							Water level 101 feet. Water is brown.
18	Do.	391	do	3-2-54	58	8	1,430					496		18	.6						
19	Do.	477	Dakota sandstone and Burro Canyon formation	3-15-54	59		1,440	6.9	68	34	219	446	383	15	.2	.6	986	309	0	61	Water has dark-green tint and odor of hydrogen sulfide.

1/ Contains 17 ppm of carbonate (CO_3)
2/ Contains 87 ppm of carbonate (CO_3)
3/ Contains 65 ppm of carbonate (CO_3)
4/ Contains 55 ppm of carbonate (CO_3)
5/ Contains 71 ppm of carbonate (CO_3)
6/ Contains 120 ppm of carbonate (CO_3)
7/ Contains 30 ppm of carbonate (CO_3)

TABLE 2.--Analyses of ground and surface waters at Towaoc.

Analysed by U. S. Geological Survey
Dissolved constituents given in parts per million.

No. on plate 1	Description	Depth (feet)	Geologic source	Date of collection	Temperature (°F)	pH	Specific conductance, in 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 (sum)	Hardness (calculated as $CaCO_3$) Total	Hardness (calculated as $CaCO_3$) Noncarbonate	Sodium in percentage of total bases	Remarks
1	Seep in wash ½ mile southwest of Towaoc			7-11-50	72		1,060	19	78	42	114	338	296	20	0.2	0.4	737	367	90	40	
2	Seep in wash 2 miles upstream from Towaoc			7-11-50	50		939	21	162	28	13	360	227	10	.1	.4	638	519	224	5	
3	Tom Root Spring			10-3-51			833	18	155	16	12	385	151	4	.1	.1	546	452	137	5	
4	Navajo Spring			10-3-51	61.5		1,050	27	141	39	39	224	372	18	.3	.6	747	512	329	14	
5	Navajo Wash			3-1-53			7,870				1,100	901[1]		166				3,530		40	
6	8	98	Alluvium	11-5-53			871	20	100	48	21	302	223	8	.2	1.2	570	447	200	9	
7	7	1,750	Navajo sandstone (?)	11-10-53			1,310					780[2]		5							Water level 55 feet. Water is black.
8	Do.	1,750	do	do			1,290					796[3]		5							Water level 160 feet. Water is black.
9	Do.	1,750	do	do			1,340					692		5							Water level 369 feet. Water is black.
10	Do.	1,750	do	do			1,300					752[4]		8							Water level 501 feet. Water is black.
11	Do.	1,750	do	do			1,300					798[5]		9							Water level 650 feet. Water is black.
12	Do.	1,750	do	do			1,390					846[6]		5							Water level 900 feet. Water is black.
13	5	65.8	Alluvium	2-7-54	56	8.5	754				17	286	161	8	.2		527	376	142	9	Sample collected after pumping 6 minutes, at 129 gpm
14	Do.	65.8	do	2-7-54	56	7	765				17	290	158	8	.2		538	376	138	9	Sample collected after pumping 6 hours, at 129 gpm
15	Do.	65.8	do	3-12-54	58		761	22	122	20	21	292	169	10	.2	2.3	510	386	147	11	Sample collected after 25 days of continuous pumping. Presence of 596 ppm of hydroxide indicates contamination from cementing.
16	6	246	Greenhorn limestone equivalent	2-22-54	58	11.7	8,900					197									
17	Do.	330	Dakota sandstone	2-27-54	54	8.5	1,440					512[7]		23							Water level 81 feet.
18	Do.	391	do	3-2-54	58	8	1,430					496		18	.6						Water level 101 feet. Water is brown.
19	Do.	477	Dakota sandstone and Burro Canyon formation	3-15-54	59		1,440	6.9	68	34	219	446	383	15	.2	.6	946	309	0	61	Water has dark-green tint and odor of hydrogen sulfide.

1/ Contains 17 ppm of carbonate (CO_3)
2/ Contains 87 ppm of carbonate (CO_3)
3/ Contains 65 ppm of carbonate (CO_3)
4/ Contains 55 ppm of carbonate (CO_3)
5/ Contains 71 ppm of carbonate (CO_3)
6/ Contains 130 ppm of carbonate (CO_3)
7/ Contains 30 ppm of carbonate (CO_3)