# WATER-SUPPLY INVESTIGATION OF SANASTEE AREA, NAVAJO INDIAN RESERVATION, SAN JUAN COUNTY, NEW MEXICO

BY

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UNITED STATES
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GEOLOGICAL SURVEY

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With a section on Quality of Water

By

J. D. Hem



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## INTRODUCTION

At the request of the Office of Indian Affairs the Ground Water Branch of the Geological Survey is now making a reconnaissance of the ground-water resources of the Navajo Indian Reservation, which occupies parts of Arizona, New Mexico, and Utah. In addition, special detailed studies are being made in areas where specific problems require immediate attention. This report of the investigation of the Sanastee area was requested because the water supply for the Sanastee school was considered unsatisfactory.

### Location

The area described in this report lies in the eastern part of the Navajo Indian Reservation, in San Juan County, N. Mex. The community of Sanastee, in the central part of the area, is about 35 miles south of Shiprock and 8 miles west of U. S. Highway 666 along a graded road. The altitude at Sanastee is about 6,000 feet. This community consists of a small boarding school and a few associated buildings. The main buildings have been condemned, and the school has not been in operation since June 1949. The nearest trading post is about 1 3/4 miles northeast of the school.

### Topography and Drainage

The Sanastee area is characterized by gentle slopes; in contrast are several small mesas and buttes that rise almost vertically from the plain. The topographic relief is moderate except in the western part, where deep canyons dissect the plain. The area is drained by Sanastee Wash and Tocito Wash, which flow eastward and enter Chaco Creek about 8 miles east of U. S. Highway 666. Chaco Creek is a tributary of the San Juan River, which flows into the Colorado River.

## Summary of Problem

Water for the Sanastee school has been obtained from a flowing well that produces a small amount of oil (well 12M-25, table 1). There are two phases of the water-supply problem: (1) Oil sometimes enters the water system in spite of attempts to remove it by a continuous overflow from an elevated storage tank; and (2) overflow from the tank and excess water from the well have been allowed to saturate the shaly ground near the school buildings, causing unstable conditions that have led to cracking of the foundations.

Officials of the Navajo Service suggested two alternative solutions to the problem: (1) Abandon the existing buildings and construct new buildings within a radius of a few hundred feet of the present site. Under this plan the Sanastee well would be plugged to seal off the oil, or a new oil-free water supply would be developed. (2) Abandon the existing location and select a site nearer U. S. Highway 666. If this plan were followed a new well would be drilled.

If a new school were built, the estimated population of the community would be about 250. On the basis of a daily per-capita consumption of 150 gallons, the total supply needed would be about 37,500 gallons per day, or about 26 gallons per minute. This is considered to be the minimum supply needed.

## Field Work and Acknowledgments

An area of about 175 square miles was studied in order to determine the most productive aquifers, the areas of recharge, and the related structural features. Geologic field work was done by J. W. Harshbarger, assisted by

W. D. McKee. Engineering field work was done by L. C. Halpenny, assisted by G. A. Lerum and H. A. Yazhe. The Quality of Water section of the report was written by J. D. Hem, district chemist, Quality of Water Branch. C. V. Theis, district geologist for ground-water investigations in New Mexico, was consulted during the work and reviewed the report. C. B. Read, in charge of the Albuquerque office of the Fuels Branch, Geologic Division, reviewed the section of the report that deals with stratigraphy.

## GEOLOGY AND GROUND-WATER RESOURCES

The geologic map of the Sanastee area is shown on plate 1. The formational boundaries and structural features were located on aerial photographs and the information was then transferred to controlled aerial mosaics from which the final map was made.

### Sedimentary Rocks and their Water-Bearing Properties

The stratigraphic section exposed in the Sanastee area is as follows:

| | |
|---|---|
| QUATERNARY (Recent) | Alluvium |
| CRETACEOUS | (Mancos shale (upper part)<br>(Mesaverde formation<br>Gallup sandstone and Dilco coal members<br>(Mancos shale (lower part)<br>(Dakota dandstone |
| JURASSIC | (Morrison formation<br>(San Rafael group<br>Todilto limestone member of Wanakah formation<br>Entrada sandstone<br>Carmel formation |

### Jurassic Rocks

The oldest rocks in the area belong to the San Rafael group, of late Jurassic age, although the lowest formation, the Carmel, does not crop out within the mapped area. Older rocks were not considered as potential aquifers because they lie too far beneath the land surface, and it is believed that sufficient water can be obtained from the younger rocks.

San Rafael group

The San Rafael group includes the Carmel formation which does not crop out in the area of this report, the Entrada sandstone, and the Todilto limestone member of the Wanakah formation. It is extremely difficult to determine the boundary between the Carmel formation and the Entrada sandstone in this region. The thickness of the San Rafael group is between 600 and 750 feet, as determined from logs of wells 12M-25 and 12R-83a. The Carmel formation is composed of red fine-grained thinbedded shaly siltstone with thin beds of fine-grained sandstone occurring at irregular intervals. The rocks above the Carmel formation consist of reddish-brown fine-grained cross-bedded to flat-bedded sandstone, including several strata of reddish thin-bedded shaly siltstone. These rocks, which are 550 to 600 feet thick, are assigned to the Entrada sandstone.

The Carmel formation is not considered to be water bearing and the well logs (table 2) do not indicate the occurrence of water in the formation. The Entrada sandstone on the other hand is a relatively good aquifer. The sand grains are usually clean and well sorted, and are only moderately cemented by calcium carbonate and minor amounts of ferric oxide. The well logs (table 2) show that substantial amounts of water were encountered in several zones within the Entrada sandstone. In well 12M-25, the Sanastee school well, oil and gas were encountered between 1,727 and 1,739 feet, 150 feet above the contact. West of the mapped area, several small seeps have been observed along the contact. The Entrada sandstone crops out over a large region west and northwest of the Sanastee area, furnishing a substantial recharge area for the collection and storage of water. The beds in a large part of this recharge area dip to the east, causing the water to move eastward, downdip toward the Sanastee area where the water is under artesian pressure.

The Todilto limestone lies conformably upon the Entrada sandstone and is the only part of the Wanakah formation recognized in this area. This limestone formerly was considered a member of the overlying Morrison formation but now is considered a member of the Wanakah formation which is equivalent to the upper part of the San Rafael group.[1] Stokes [2] is also of the opinion that the Todilto limestone should be placed in the San Rafael group; he believes that the sedimentary environment is more related to the San Rafael sedimentation than to conditions in Morrison time.

The Todilto limestone in the Sanastee area is 15 to 20 feet thick and consists of bluish-gray, fine-grained to aphanitic, thin-bedded impure limestone. This unit is resistant to erosion and forms a prominent bench in the sandstone slopes, and in some places forms a resistant cap rock on the Entrada sandstone.

No wells are known to produce water from the Todilto and it is not considered an aquifer because of the impervious character of the rock.

<u>Morrison formation</u>

The Morrison formation of late Jurassic age lies conformably upon the Todilto limestone. A definite boundary is established in this area by the contact between the limestone and sandstone of the Morrison. In some areas the Morrison formation is easily subdivided into several members.[3] Each of these

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[1] Baker, A. A., Dane, C. H., and Reeside, J. B., Sr., Revised correlation of Jurassic formation of parts of Utah, Arizona, New Mexico, and Colorado: Amer. Assoc. Petroleum Geologists Bull., vol. 31, no. 9, pp. 1664-1668, 1947.

[2] Stokes, W. L., Morrison formation and related deposits in and adjacent to the Colorado Plateau: Geol. Soc. America Bull., vol. 55, p. 984, 1944.

[3] Gregory, H. E., the San Juan country, a geographic and geologic reconnaissance of southeastern Utah: U. S. Geol. Survey Prof. Paper 188, pp. 58-60, 1938.

members is defined by its own distinctive lithology, which includes aeolian sandstone, fluviatile sandstone, siltstone, mudstone, and conglomerate. In the Sanastee area, however, it is difficult to subdivide the Morrison formation into members because there are no sharply contrasting lithologic changes. The Morrison formation crops out only in the western part of the area. In this locality the rocks consist of pinkish-gray to white, medium-grained, thin-bedded, weakly cemented sandstones that alternate with gray, black, green and red, thin-bedded siltstones. These alternating beds form a rough irregular slope, usually partly concealed by talus. The thickness of the Morrison formation in the Sanastee area is 1,100 to 1,200 feet. In general, the lower 600 to 700 feet consists largely of sandstone, whereas the upper part contains nearly equaly amounts of siltstone and sandstone.

The Morrison formation contains the essential features of a relatively good aquifer. The grains in the sandstones are fairly well sorted and loosely cemented. The siltstones usually contain enough sand grains to make them somewhat pervious. Table 2 shows that water was encountered in several of the thicker sandstone units that occur throughout the formation. In addition to the outcrops shown on plate 1, outcrops west of the area mapped provide an excellent recharge area. These beds dip to the east, causing the ground water to move in that direction. The water is under artesian pressure, as evidenced by flowing wells 12M-25, 12R-83, and 12R-84. Sanastee Wash crosses the Morrison 6 to 7 miles west of the school, providing an important source of recharge. It is believed that water could be obtained from the Morrison formation almost anywhere in the Sanastee area, and that in all probability the water would be under sufficient artesian pressure to flow from a well.

Dakota sandstone

The oldest Cretaceous rocks in the Sanastee area are represented by the Dakota sandstone, which is separated from the Morrison formation by an erosional unconformity. The contact is not everywhere easily detected because the lithology of the Morrison formation and Dakota sandstone is similar in many places. Where the unconformity can be detected, the erosion channels have a relief of several inches to several feet. In the Sanastee area the Dakota sandstone is composed of light-gray, medium-grained, thin-bedded, well-cemented sandstones that alternate with gray and black thin-bedded siltstones. Thin seams of low-grade coal occur at irregular intervals. The sandstones form resistant ledges and the intervening silty beds form slopes. The thickness of this formation, as determined from well logs (table 2), ranges from 16 feet to more than 100 feet. Because the lithology of the Dakota sandstone is similar to that of part of the Morrison rocks, it is difficult to determine the thickness accurately.

The Dakota sandstone is known to be a good aquifer over many large areas. In the Sanastee area the formation is relatively thin but contains thick units of sandstone in a few places. These sandstones provide reservoir space and allow water to move relatively freely. A study of the well logs indicates that these thicker sandstone units contain a small amount of water. If wells were spaced at wide intervals it would be possible to obtain water in limited amounts from the Dakota sandstone. The water probably would be under artesian pressure, as the structure of the Dakota sandstone is conformable to that of the Morrison formation.

Mancos shale

The Mancos shale lies conformably upon the Dakota sandstone. The boundary is easily observed owing to the sharp contrast between the black shale and the underlying light-gray sandstone. The Mancos shale has an almost homogeneous lithology and is composed of dark-gray to black fissile carbonaceous shale. In the Sanastee area the Mancos shale is split into two parts by a tongue of the Gallup sandstone and Dilco coal members of the Mesaverde formation (fig. 1). The lower part of the Mancos is bluish-gray fissile shale, with an average thickness of 750 feet. The upper part is grayish-brown arenaceous fissile shale and siltstone, with an average thickness of 950 feet.

Although the Mancos shale is generally considered older than the Mesaverde formation, the upper part of the shale in the Sanastee area is younger than the underlying Gallup sandstone and Dilco coal members of the Mesaverde formation (fig. 1). The intertonguing relation and depositional history of these Cretaceous sediments are discussed more fully by Pike[4] than in this report. In brief, these deposits are related to the transgression and regression of the sea that covered this area in Upper Cretaceous time. The shale was deposited during a period when the sea had transgressed to the south, whereas the tongues of sandstone represent a regressive stage when the seas withdrew to the north.

The Mancos shale is not an aquifer but acts as an impervious barrier between ground waters in the underlying and overlying sandstones.

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[4] Pike, W. S., Jr., Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. America Memoir 24, pp. 13-25, 1947.
America M

Mesaverde formation

In the Sanastee area the Gallup sandstone and Dilco coal members of the Mesaverde formation occur as a tongue within the Mancos shale (fig. 1). This tongue is divided on the basis of lithology into three units:
1. The lower part consists of a light-gray, fine-grained, thin-bedded sandstone that has been correlated with the Gallup sandstone member of the Mesaverde formation by Pike.[5] 2. Thin units of alternating sandstones, carbonaceous siltstones and scattered coal seams which are correlated with the lower part of the Dilco coal member. [6] 3. A light-gray, coarse-grained, cross-bedded sandstone which, according to Pike, may correspond to the "stray sandstone" of Sears. [7] The total thickness of the three units averages about 100 feet. They have been referred to locally as the Tocito sandstone lentil of the Mancos shale, from the exposures in Tocito Wash. However, as Pike has correlated them with the Gallup sandstone and Dilco coal members of the Mesaverde formation, the name Tocito does not appear to be valid. For the purpose of this report Pike's correlation has been used.

The Gallup sandstone member and the "stray sandstone" of the Mesaverde formation have good water-bearing properties. The sand grains in both are clean and well sorted and are not well cemented, especially in the "stray sandstone." These characteristics allow ground water to move through the sandstone freely but because it is relatively thin the reservoir capacity is not large. The recharge area of these members is not as large as recharge areas of the Morrison and Entrada formations. In the vicinity of Tocito trading post and along the northeast flank of Tocito dome the occurrence of seeps in the Gallup sandstone member shows that it contains some water.

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[5] Pike, W. S., Jr., op. cit., p. 28, 1947.

[6] Idem, p. 28.

[7] Sears, J. D., Hunt, C. B., and Hendricks, T. A., Transgressive and regressive Cretaceous deposits in southern San Juan Basin, N. Mex.: U. S. Geol. Survey Prof. Paper 193-F, p. 113, 1941.

## Quaternary Deposits

Alluvium of Recent age occurs along Sanastee Wash and Tocito Wash (pl. 1) and consists of a mixture of shale, silt, sand, pebbles, and boulders deposited in long shallow depressions along the stream courses. The finer materials were derived from the surrounding Cretaceous and Jurassic rocks. The coarser materials are mostly igneous fragments from the volcanic rocks that crop out west of the Sanastee area. The alluvium ranges in thickness from 5 to 25 feet.

Water moves freely through the unconsolidated alluvium, as evidenced by several seeps along the washes. Nearly all these seeps are located where impervious shale beds force underflow to the surface. Several dug wells obtain water from the alluvium.

## Igneous Rocks

Outcrops of igneous rocks in the area consist of one small plug and two narrow dikes south of Tocito Wash. These rocks are believed to be genetically related to the volcanic necks that lie southeast of the Sanastee area. The igneous rocks do not yield water.

## Structure

The Sanastee area lies in the west-central part of the San Juan Basin and contains several local anticlinal folds (pl. 1). The largest of these is Beautiful Mountain anticline, a rather narrow fold. The axis of this anticline trends approximately N. 20°W. through the central part of the area. Near the northern boundary of the area the axis swings eastward to about N. 10° E., continuing for a distance of 5 miles north of the mapped area. The northern half of the anticline is folded asymmetrically, as the eastern flank dips 9° to 13° and the western flank dips 1° to 2°. The southern half of the anticline is nearly symmetrical, as both flanks dip from 1° to 3°.

degrees. The southern half of the anticline is nearly symetrical, as both flanks dip from 1 to 3 degrees.

A small, prominent elongated dome, known as the Tocito dome, lies in the northeast part of the area. The major axis of this dome trends about N. 40° W. The length of the dome is about twice as great as the width, and the northeastern and southwestern flanks are nearly symetrical. The southern end of the dome is several hundred feet north of Sanastee Wash, and the northern end is 1 mile northwest of well 12R -84. A minor east-west fault with a displacement of about 50 feet cuts across the center of the dome. This fault is not shown on plate 1.

A relatively shallow asymmetrical syncline trending N. 30° W. lies between Beautiful Mountain anticline and Tocito dome. Another asymmetrical syncline trending about N. 20° W. lies west of the southern half of Beautiful Mountain anticline. The eastward dip of the beds in the western limb of this syncline ranges from 1 to 11 degrees. In the western part of the area the dip of the beds becomes increasingly greater.

These eastward-dipping strata are believed to be a part of the Fort Defiance monocline. The folded structures of the Sanastee area are pertinent to the movement of ground water. The greater part of the recharge area is located on the eastward-dipping strata that form the lower part of the Fort Defiance monocline. The recharge area is several hundred feet higher in elevation than the wells in the Sanastee area (table 1). It is evident that the ground water should be under artesian pressure at the wells. Furthermore, well tests indicate that the hydrostatic pressure is sufficient to cause ground water to move through the folded structures.

## WATER SUPPLIES

An investigation was made of the wells and most of the springs in the Sanastee area, and the results of these studies are given in tables 1, 2, and

3. The investigation showed that only the Dakota? sandstone, the Morrison formation, and the Entrada sandstone will yield sufficient water to supply the proposed school. Water was encountered in one or more of these formations by four deep wells (12M-25, 12R-83, 12R-83a, 12R-84, table 2). One of the four deep wells (12M-25) is on Beautiful Mountain anticline at Sanastee school. The other three wells are on Tocito dome, about 7 miles northeast of Sanastee. The following sections discuss the water supplies of the area.

Well at Sanastee school

Well 12M-25 has been flowing almost without interruption since 1925. A study of the well log (table 2) shows that most of the water is produced from the Morrison formation and the Dakota ? sandstone, which overlie the Todilto limestone. The oil and a small amount of the water is produced from the Entrada sandstone.

Tests were made on the well to determine the maximum shut-in pressure, the maximum rate of flow, and the physical characteristics of the aquifers. The flow from the well was shut off for 4.8 hours by a valve at the orifice of the well. Data obtained from observing the build-up in pressure (see fig. 2 a) made it possible to compute the hydrostatic pressure that would have built up if the flow had been uct off indefinitely. This hydrostatic pressure was computed to be equal to the pressure required to support a column of water 129 feet in height above the measuring point. After the pressure data were collected, the valve was opened and measurements were made of the decline in rate of flow with respect to time. The rate of flow became approximately constant at 57 gallons per minute about 4 hours after the valve was opened (see fig. 2 b). Computations of transmissibility, using a method developed by Theis[7], indicate that the aquifers at Sanastee are moderately permeable, relative to other sandstone aquifers. Using a discharge of 57 gallons per

7/ 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. 520, 1935.

point. After the pressure data were collected, the valve was opened and measurements were made of the decline in rate of flow with respect to time. The rate of flow became approximately constant at 57 gallons per minute about 4 hours after the valve was opened (see fig. 2b). Computations of transmissibility, using a method developed by Theis,[8] indicate that the aquifers at Sanastee are moderately permeable, relative to other sandstone aquifers. With a discharge of 57 gallons per minute (fig. 2b) and the computed static head of 129 feet above the measuring point, the specific capacity of the well was computed to be about 0.45 gallon per minute per foot of drawdown.

The results of the tests on well 12M-25 indicate that the aquifers in the Sanastee area would yield sufficient water to supply the proposed new school.

## Wells on Tocito Dome

The three wells on Tocito dome (12R-83, 12R-83a, and 12R-84) were drilled in search of oil. Two of the wells were abandoned as oil tests and, because fresh water was encountered, they were sold to the Federal Government for use as water wells. The third well (12R-83a) is capped, and no tests could be made to determine the amount of available water.

The discharge and the maximum hydrostatic pressure were measured on wells 12R-83 and 12R-84. The open-flow rate of discharge of well 12R-83 was 19 gallons per minute and the computed hydrostatic pressure at the end of 3 hours was equivalent to the pressure required to support a column of water about 37 feet above the land surface. The open-flow rate of discharge of well 12R-84 was 11 gallons per minute and the computed hydrostatic pressure at the end of 3 hours was equivalent to the pressure required to support a

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. 520, 1935.

column of water about 30 feet above the land surface. The measurements showed that the combined flow of both wells would supply the 26 gallons per minute needed for the proposed school.

Calculations were made to estimate the drawdown in each well, assuming that water for the proposed school would be supplied from either well by pumping part of each day and collecting the flow during the remaining part of the day. Assuming an 8-hour daily pumping period and a 4-hour period during which the piezometric surface is recovering from the pumping level to the level of maximum flow, the well would flow at the maximum rate of 19 gallons per minute for 12 hours per day and at a lower rate during the latter stages of the 4-hour period of recovery. The discharge during the 4-hour recovery period is not included, but constitutes a factor of safety, in the following calculations to determine the required pump discharge and the resulting drawdown.

| | |
|---|---|
| Total water needed per 24 hours: | 37,500 gallons |
| Water collected during 12-hour flowing period (60 min. x 12 hrs. x 19 gpm.): | 13,680 gallons |
| Water collected during 4-hour recovery period: | 0 |
| Water that must be pumped during the remaining 8 hours (37,500 - 13,680): | 23,820 gallons |
| Pumping rate required (23,820 gal. ÷ 60 min. x 8 hrs.): | 49.6 gallons per minute |
| Drawdown when pumping (50 g.p.m. ÷ 1/2 g.p.m. per ft. of drawdown): | 100 feet |

Applying a similar procedure to well 12R-84, the required pumping rate would be 62 gallons per minute and the drawdown would be about 170 feet below the land surface.

Springs and shallow wells

The locations of the springs studied in the Sanastee area are shown on plate 1, and records of these springs are given in tables 1 and 3. Two springs (S-1 and S-2) issue from the lower part of the Mancos shale, along the banks of Sanastee Wash. The operator of Sanastee trading post reported that the flow of spring S-2 increased in 1948, after a seismograph crew set off subsurface explosions in this vicinity. A resident Indian reported that a seismograph test hole was drilled at the spring. Whatever the cause, the authors assume that as a result of the seismograph testing program a passage was opened through the shale, which allowed water from the Dakota sandstone to flow to the land surface. A third spring (S-3) issues from alluvial fill in the bottom of the wash, and represents underflow forced to the surface by impervious shale beds. A fourth spring (S-5) is on the northeastern limb of Tocito dome, and issues from the Gallup sandstone member of the Mesaverde formation.

Several seeps along Sanastee Wash issue from the alluvial fill, and one well (S-4) formerly was used to obtain water from the fill. The underflow of Sanastee Creek was estimated to be about 50 gallons per minute at the time of the investigation. Impervious shale beds force underflow to the surface at several localities between Sanastee school and U. S. Highway 666. Marshy lands supporting swamp grass occur in some of these localities, and incrustations of salt along the edges of the stream are common.

QUALITY OF WATER

By

J. D. Hem

The analyses of seven water samples in table 3 show the chemical character of ground waters in the vicinity of Sanastee. Two samples, which were collected from well 12M-25 9 months apart, show no significant differences in quality. Wells 12R-83 and 12R-84, northeast of Sanastee, yield water with chemical character similar to water from well 12M-25. The water from these three wells is derived principally from the Dakota sandstone and the Morrison formation. The water from wells 12R-83 and 12R-84 has a slightly higher dissolved-solids content than water from well 12M-25. This difference may be caused by one or both of the following factors: (1) Local variation in soluble salts in the Dakota sandstone and the Morrison formation; and (2) variations in the proportions of water coming from the different water-bearing beds in the formations. The low concentrations of calcium and magnesium in the water from these three wells indicates that natural softening of the water by base exchange may occur within the Dakota and Morrison formations.

Spring S-1 issues from Mancos shale and yields water containing rather large amounts of dissolved solids, mostly calcium and sulfate. Spring S-2, nearby, yields water lower in dissolved-solids concentration and much softer, the principal constituents being sodium, bicarbonate, and sulfate. As already stated in this report, spring S-2 is believed to obtain some water from the underlying Dakota sandstone, and the discharge may represent a mixture of waters from the Dakota sandstone and the Mancos shale. Spring S-3 issues in the bottom of Sanastee Wash, and the analysis of a sample from this spring is believed to represent the quality of water in the Quaternary alluvium along the wash. This water is somewhat more highly mineralized than the water from spring S-1 and from spring S-2. Spring S-5 is reported to issue from the Gallup sandstone member of the Mesaverde formation on the northeast side of Tocito dome. On the basis of the analyses, water from spring S-5 is of better quality than water from the other springs in the area.

Analyses of water from the Dakota sandstone and the Morrison formation in the Sanostee area show low dissolved solids and hardness. The water from these formations is of good quality for domestic use. Water from the Mancos shale and from the alluvial fill along Sanostee Wash is too highly mineralized to be satisfactory for domestic use. Water from well 12M-25 is not satisfactory for domestic use because of its oil content, but if the oil were plugged off the water would be of the best quality of those sampled in the area.

## METHODS FOR OBTAINING SUITABLE WATER

### Well at Sanostee School

According to the log of well 12M-25, oil is entering below the Todilto limestone. A concrete plug placed at the top of the limestone, at a depth of 1,420 feet, would seal off the oil. However, this would also seal off one water-bearing stratum (1,845 to 1,890 feet) and would reduce the well discharge. To insure a tight seal the "squeeze" method, used by commercial oil-well cementing companies, should be tried. After the lower part of the well has been tightly sealed off and the upper part has been thoroughly cleaned out, the well probably will produce an adequate water supply of suitable quality for the proposed school.

A new well could be drilled at Sanostee school in the event that well 12M-25 is used for irrigation or is abandoned. The new well should be about half a mile from well 12M-25, and should be drilled to a depth of about 1,400 feet, in order to penetrate the Morrison formation.

## Wells on Tocito Dome

The discussion of the wells on Tocito dome under the heading "Water Supplies" indicates that an adequate supply is already developed for the proposed school.

## Site between Sanastee School and U. S. Highway 666

Construction of a new school east of the abandoned school would require the drilling of a well. Investigation indicated that water could be obtained at any point between the abandoned school and U. S. Highway 666. If the site selected is about 3½ miles west of the highway, the following stratigraphic section would be encountered.

| Formation | Age | Water-bearing character | Thickness (feet) | Depth to base of formation (feet) |
|---|---|---|---|---|
| Mancos shale (upper part) | Cretaceous | Non-water-bearing | 100-200 | 100-200 |
| Gallup sandstone member and Dilco coal member of Mesaverde formation | do. | Possibly water-bearing | 200± | 300-400 |
| Mancos shale (lower part) | do. | Non-water-bearing | 750± | 1,050-1,150 |
| Dakota sandstone | do. | Water-bearing | 60-100 | 1,110-1,250 |
| Morrison formation | Jurassic | do. | 1,150± | 2,260-2,400 |

According to the section above, determined from a study of well logs, areal distribution of formations, and structural relations in the Sanastee area, a well at this site should be drilled to a minimum depth of 1,100 feet and a possible maximum depth of 2,400 feet. Water would be encountered in the Dakota sandstone but in all probability the major part of the water would have to be obtained by drilling into the Morrison formation.

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made for the development of a suitable water supply for the Sanastee school:

1. About 37,500 gallons per day of potable water will be needed in the Sanastee

area when the proposed school is constructed.

2. The Sanastee well (12M-25) provides an adequate quantity but the water is contaminated with oil from the Entrada. Water from the well would be of suitable quality for domestic use except for the associated oil.

3. The oil in the Sanastee well can be sealed off by placing a plug in the well at the top of the Todilto limestone, at a depth of about 1,400 feet. In order to insure a tight seal, it is recommended that the plugging be done by an oil-well cementing company.

4. A new well could be drilled at Sanastee to furnish a water supply for the proposed school if the Sanastee well is used for other purposes. A new well should be at least half a mile from the existing well, and should be drilled to a depth of about 1,400 feet.

5. The required amount of water for the proposed school is available from two flowing wells about a mile apart on Tocito dome. This water is considered suitable for domestic use. Either of these wells could supply the school if a pump were installed.

6. Construction of a new school east of Sanastee school would require the drilling of a well. Water could be obtained at any point between Sanastee school and U. S. Highway 666. If the site selected were 3½ miles west of the highway, the well should be drilled to a minimum depth of 1,100 feet or to a maximum depth of 2,400 feet. The water would be under artesian pressure, and the major part would be obtained from the Morrison formation. Analyses of water samples from the other wells in the area show that water from a well in this vicinity probably would be suitable for domestic use.

Table 1.--Records of wells and springs in Sanastee area, San Juan County, New Mexico
(All wells are drilled unless otherwise noted in "Remarks" column)

| Office number | Distance from Sanastee school | Owner | Date completed | Altitude above sea level (feet) | Depth of well (feet) | Diameter of well (inches) |
|---|---|---|---|---|---|---|
| d/ 12N-25 | ¼ mile W. | Navajo Service | 1925 | 5,982 | 3,290 | 15½ |
| d/ 12R-83 | 6¼ miles NE. | do. | 1922? | 5,865 | 3,015 | 16 |
| 12R-83a | 6 miles NE. | Continental Oil Co., et al. | 1943 | 5,852 | 6,903 | 16 |
| d/ 12R-84 | 7 miles NE. | Navajo Service | 1924? | 5,824 | 1,430 | 16 |
| d/ S-1 | ½ mile N. | do. | - | - | - | - |
| d/ S-2 | do. | do. | - | - | 5 | 48 |
| d/ S-3 | do. | do. | - | - | - | - |
| S-4 | 1 3/4 miles ENE. | Sanastee Trading Post | - | - | 30 | 6 |
| S-5 | 8½ miles ENE. | Navajo Service | - | - | - | - |

a/ Measurements are feet of head above outlet of discharge pipe, measured with pressure gage.

b/ F, flowing.

Records obtained by H. A. Yazhe, G. A. Lerua, and A. D. Pulido
(See plate 1 for locations of wells and springs.)

| Office number | Water level: Depth below measuring point (feet) a/ | Water level: Date of measurement, 1949 | Pump and power b/ | Use of water c/ | Temp. °F | Remarks |
|---|---|---|---|---|---|---|
| 12M-25 | +128.95 | Aug. 30 | F | D,S | 69 | Oil test, now used as water well. Supplies Sanastee school. Produces slugs of oil from Entrada sandstone. Measured flow of water, 59 gallons per minute, Aug. 30, 1949. See log. |
| 12R-83 | + 37.55 | Sept.24 | F | I,S | 77 | Oil test. Measured flow of water, 19 gallons per minute, Dec. 19, 1949. SW¼SW¼ sec. 17, T. 26 N., R. 18 W. See log. |
| 12R-83a | - | - | None | N | 75 | Oil test, capped. NW¼SW¼ sec. 17, T. 26 N., R. 18 W. See partial log. |
| 12R-84 | + 29.5 | Aug. 31 | F | I,S | 76½ | Oil test. Measured flow of water, 11 gallons per minute, Aug. 31, 1949. Sec. 8, T. 26 N., R. 18 W. See log. |
| S-1 | Spring | - | F | N | - | Flows into Sanastee Wash. Estimated discharge, Aug. 31, 1949, 5 gallons per minute. |
| S-2 | do. | - | F | D,S | - | Deepened by digging. Estimated discharge, Aug. 31, 1949, 20 gallons per minute. |
| S-3 | do. | - | F | N | - | In bed of Sanastee Wash. Estimated discharge, Aug. 31, 1949, 50 gallons per minute. |
| S-4 | 10 e/ | Aug. 31 | None | N | - | Produced water from alluvial fill of Sanastee Wash. |
| S-5 | Spring | - | F | D,S | 34 | Issues from sandstone outcrop on eastern side of Tocito dome. Estimated discharge, 2 gallons per minute, Dec. 19, 1949 |

c/ D, domestic; S, stock; I, irrigation; N, none.
d/ See table 3 for analysis of water from this well or spring.
e/ Water level reported.

Table 2.-Logs of wells in Sanastee area, San Juan County, New Mexico

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Driller's log of well 124-25 | | |
| Navajo Service, owner. At Sanastee Day School. | | |
| Lower part of Mancos shale (Cretaceous) | | |
| Gray shale - - - - - | 65 | 65 |
| Lime shell - - - - - | 4 | 69 |
| Sandy shale - - - - | 31 | 100 |
| Sand, water at 105 feet | 10 | 110 |
| Sandy gray shale - - | 140 | 250 |
| Lime shell - - - - - | 5 | 255 |
| Black shale - - - - | 20 | 275 |
| Dakota sandstone(Cretaceous) | | |
| Sand, water at 280-320 feet - - - - - - - | 45 | 320 |
| Black shale - - - - | 5 | 325 |
| Sand - - - - - - - - - | 10 | 335 |
| Coal - - - - - - - - - | 5 | 340 |
| Morrison formation(Jurassic) | | |
| Sand - - - - - - - - - | 5 | 345 |
| White shale - - - - | 70 | 415 |
| Red rock - - - - - - | 20 | 435 |
| Green and white shale | 15 | 450 |
| Red rock - - - - - - | 25 | 475 |
| Gray sand - - - - - | 5 | 480 |
| Red sand, water at 540-575 feet - - - - - | 100 | 580 |
| White sand - - - - - | 20 | 600 |
| Red sand, water at 710 feet - - - - - - - | 145 | 745 |
| Hard lime shell - - | 20 | 765 |
| Red sand - - - - - - | 105 | 870 |
| Sandy red shale - - | 20 | 890 |
| Red sand - - - - - - | 65 | 955 |
| Sandy red shale - - | 20 | 975 |
| Red sand - - - - - - | 30 | 1,005 |
| Sandy red shale - - | 20 | 1,025 |
| Red rock - - - - - - | 105 | 1,130 |
| Red sand, water at 1,180 feet - - - - - - - | 50 | 1,180 |
| Pink shell - - - - - | 20 | 1,200 |
| Red sand - - - - - - | 10 | 1,210 |
| Hard pink sand - - - | 15 | 1,225 |
| Hard pink shell - - | 35 | 1,260 |
| Lime shell - - - - - | 5 | 1,265 |
| Red sand - - - - - - | 20 | 1,285 |
| White sand, water at 1,290 feet - - - - | 10 | 1,295 |
| White sand, heaving | 15 | 1,310 |
| Log of well 124-25 - Cont. | | |
| Morrison formation(Jurassic) - Cont. | | |
| Red sand - - - - - | 15 | 1,325 |
| Hard red sand - - | 75 | 1,400 |
| Sandy pink shale - | 20 | 1,420 |
| San Rafael group (Jurassic) | | |
| Todilto limestone member of Wanakah formation | | |
| Limestone - - - - | 15 | 1,435 |
| Entrada sandstone | | |
| Brown sand - - - - | 20 | 1,455 |
| Red sand - - - - - | 40 | 1,495 |
| Sandy red shale - | 45 | 1,540 |
| Red shale - - - - | 35 | 1,575 |
| Red sand - - - - - | 5 | 1,580 |
| Red shale - - - - | 10 | 1,590 |
| Hard red sand - - | 80 | 1,670 |
| Red sand, oil and gas at 1,727-1,739 feet | 69 | 1,739 |
| Sandy red shale - | 51 | 1,790 |
| Red sand, water at 1,845 feet - - - - | 100 | 1,890 |
| Carmel (?) formation | | |
| Red shale - - - - | 35 | 1,925 |
| Red sand - - - - - | 5 | 1,930 |
| Red shale - - - - | 250 | 2,180 |
| Glen Canyon (?) group (Jurassic?) | | |
| Cherty gray lime - | 95 | 2,275 |
| Hard shale with red lime shells - - - - - | 140 | 2,415 |
| Red lime - - - - - | 35 | 2,450 |
| Hard shale with red lime shells - - - | 80 | 2,530 |
| Soft red shale - - | 70 | 2,600 |
| Red shale - - - - | 79 | 2,679 |
| No record - - - - | 611 | 3,290 |
| TOTAL DEPTH - - - - - | | 3,290 |

Casing record: $15\frac{1}{2}$-inch casing set at 222 feet and cemented below 155 feet; $12\frac{1}{2}$-inch casing set at 465 feet with no cement; 10-inch casing set at 1,485 feet with no cement; $8\frac{1}{4}$-inch casing set at 2,180 feet with no cement. The 10-inch and $8\frac{1}{4}$-inch casing is believed to have been removed.

Table 2.-Logs of wells in Sanastee area-Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Log of well 12R-83 | | |
| Navajo Service, owner | | |
| Gypsy Oil Co., Tocito No. 1 | | |
| SW¼SW¼ sec. 17, T. 26 N., R. 18 W. | | |
| Gallup sandstone member and Dilco coal member of Mesaverde formation (Cretaceous) | | |
| Gray sandstone - - - | 45 | 45 |
| Sandstone and shale | 55 | 100 |
| Lower part of Mancos shale (Cretaceous) | | |
| Sandy gray shale - - | 250 | 350 |
| Sandy black shale - | 359 | 709 |
| Limy black shale - - | 50 | 759 |
| Shaly black lime - - | 9 | 768 |
| Limy black shale - - | 5 | 773 |
| Hard shell - - - - - | 1 | 774 |
| Limy black shale - - | 68 | 842 |
| Dakota sandstone (Cretaceous) | | |
| Sand, water-bearing | 25 | 867 |
| Sandy black shale - | 3 | 870 |
| Shaly gray sand - - | 4 | 874 |
| White to light-gray sand | 12 | 886 |
| Sand, coal, and shale | 4 | 890 |
| Black shale - - - - | 1 | 891 |
| Morrison formation (Jurassic) | | |
| White to light-gray sand | 19 | 910 |
| Shaly white to light-gray sand - - - - - | 9 | 919 |
| Black shale - - - - | 7 | 926 |
| Gray water sand, water level 75 feet below land surface - - - | 37 | 963 |
| Coal - - - - - - - - - | 3 | 966 |
| Coal and dark-gray shale | 8 | 974 |
| Limy sand and shale | 1 | 975 |
| Coal - - - - - - - - - | 5 | 980 |
| Dark-gray and black shale - - - - - - - - | 3 | 983 |
| Sandy light-gray shale | 5 | 988 |
| Black shale - - - - | 3 | 991 |
| Cemented gray sand - | 2 | 993 |
| White to light-gray water sand, well flowing, tastes of sulfur - | 50 | 1,043 |
| Fine-grained green sand | 5 | 1,048 |
| Log of well 12R-83 - Cont. | | |
| Morrison formation (Jurassic)-Cont. | | |
| Sandy light-green shale | 48 | 1,096 |
| Fine-grained red sand - | 7 | 1,103 |
| White sand and green shale - - - - - - - - - | 11 | 1,114 |
| White sand, hole full of water - - - - - - - - - | 42 | 1,156 |
| Sandy shale - - - - - - - | 12 | 1,168 |
| Sand and shale - - - - | 7 | 1,175 |
| White water sand - - - | 25 | 1,200 |
| Red sand and green shale | 10 | 1,210 |
| Red sand - - - - - - - - | 5 | 1,215 |
| White shale - - - - - - - | 10 | 1,225 |
| White sand, hole full of water at 1,310 feet - | 95 | 1,320 |
| Hard pink sand - - - - | 7 | 1,327 |
| Red sand - - - - - - - - - | 33 | 1,360 |
| White sand - - - - - - - | 5 | 1,365 |
| Red sand - - - - - - - - - | 130 | 1,495 |
| White sand - - - - - - - | 105 | 1,600 |
| Hard red sand - - - - - - | 20 | 1,620 |
| Green "slate" - - - - - - | 5 | 1,625 |
| White sand, caving - - | 70 | 1,695 |
| Red sand, caving, hole full of water - - - - | 53 | 1,748 |
| Red shale - - - - - - - - - | 82 | 1,830 |
| Gray sand, hole full of water - - - - - - - - - | 50 | 1,880 |
| White sand, caving - - | 85 | 1,965 |
| Gray sand - - - - - - - - | 40 | 2,005 |
| Red sand - - - - - - - - | 55 | 2,060 |
| Red shale - - - - - - - - | 15 | 2,075 |
| Red sand - - - - - - - - | 20 | 2,095 |
| Gray shale - - - - - - - | 15 | 2,110 |
| San Rafael group (Jurassic) | | |
| Todilto limestone member of Wanakah formation | | |
| Sandy lime, water at 2,118 feet - - - - - - - | 17 | 2,127 |
| Entrada sandstone | | |
| White shale - - - - - - - | 38 | 2,165 |
| Sand, hole full of water - - - - - - - - - | 30 | 2,195 |
| Red mud - - - - - - - - - | 20 | 2,215 |
| Red shale - - - - - - - - | 90 | 2,305 |
| Sand - - - - - - - - - - - | 40 | 2,345 |
| Red shale, some water | 181 | 2,526 |
| Red sand, hole full of water at 2,540 feet - | 39 | 2,565 |

Table 2.-Logs of wells in Sanastee area-Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Log of well 12R-83 - Cont. | | |
| San Rafael group(Jurassic)-Cont. | | |
| Entrada sandstone-Cont. | | |
| Sandy shale - - - - - | 75 | 2,640 |
| White lime - - - - - | 10 | 2,650 |
| Red shale, water at 2,685 feet - - - - - | 115 | 2,765 |
| Hard lime - - - - - | 5 | 2,770 |
| Carmel (?) formation | | |
| Red shale - - - - - - | 245 | 3,015 |
| TOTAL DEPTH - - - - - - | | 3,015 |
| Log of well 12R-83a | | |
| Continental Oil Co., Stanolind Oil & Gas Co., and Standard Oil Co. of Texas | | |
| Tocito Unit no. 1 | | |
| $NW\frac{1}{4}SW\frac{1}{4}$ sec. 17, T. 26 N., R. 18 W. | | |
| Lower part of Mancos shale (Cretaceous) | | |
| No log - - - - - - - - | 340 | 340 |
| Dark-gray shale - - - | 10 | 350 |
| Silty dark-gray shale | 20 | 370 |
| Dark-gray shale - - - | 270 | 640 |
| Calcareous dark-gray shale - - - - - - - - | 40 | 680 |
| Fossiliferous and calcareous dark-gray shale | 10 | 690 |
| Calcareous dark-gray shale - - - - - - - - - | 100 | 790 |
| Silty calcareous shale | 60 | 850 |
| Dakota sandstone(Cretaceous) | | |
| Light-buff sandstone - | 40 | 890 |
| Silty, fine-grained gray sandstone - - - | 20 | 910 |
| Silty gray sandstone and sandy shale - - - | 20 | 930 |
| Light-gray sandstone - | 30 | 960 |
| Morrison formation (Jurassic) | | |
| Light gray sandstone and gray shale - - - - - | 30 | 990 |
| Sandy gray shale - - - | 10 | 1,000 |
| Sandy gray shale and shaly sandstone - - - | 10 | 1,010 |
| Coarse gray sandstone with reddish burnt coal - - - - - - - - - | 10 | 1,020 |
| Shaly gray sandstone - | 10 | 1,030 |
| Shaly gray sandstone, gray shale and loose burnt coal - - - - - - | 10 | 1,040 |

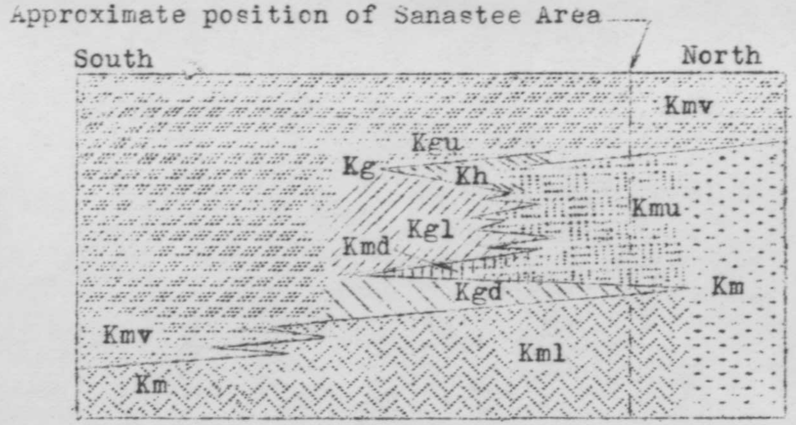
| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Log of well 12R-83a - Cont. | | |
| Morrison formation(Jurassic)-Cont. | | |
| Shaly gray sandstone | 10 | 1,050 |
| Light-gray, white and green clay shale - | 20 | 1,070 |
| Sandy, light-gray and white clay shale - | 20 | 1,090 |
| Sandy, light-green and gray clay shale - | 30 | 1,120 |
| Coarse-grained white sandstone - - - - | 20 | 1,140 |
| Sandy light-green and gray clay shale - | 20 | 1,160 |
| Sandy shale - - - - | 10 | 1,170 |
| Black shale and coal | 20 | 1,190 |
| Light-green clay shale and white sandstone | 30 | 1,220 |
| Coarse-grained white clayey sandstone - | 50 | 1,270 |
| Light-pink sandstone | 40 | 1,310 |
| Shaly coarse-grained sandstone - - - - | 20 | 1,330 |
| Light-pink sandstone | 240 | 1,570 |
| Light-gray sandstone | 120 | 1,690 |
| Sandstone and bentonitic shale - - - - - - | 20 | 1,710 |
| Gray shale - - - - | 80 | 1,790 |
| Sandy shale - - - - | 80 | 1,870 |
| Light-pink sandstone | 10 | 1,880 |
| Variegated shale - | 40 | 1,920 |
| Sandstone and variegated shale - - - - - - | 70 | 1,990 |
| Sandy gray shale - | 40 | 2,030 |
| Shaly sandstone - - | 10 | 2,040 |
| Variegated shale - | 40 | 2,080 |
| Sandy variegated shale | 50 | 2,130 |
| San Rafael group (Jurassic) | | |
| Todilto limestone | | |
| Variegated shale and limestone - - - - | 60 | 2,190 |
| TOTAL DEPTH | | 6,903 |

Table 2.-Logs of wells in Sanastee area-Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Driller's log of well 12R-84** | | |
| Navajo Service, owner. | | |
| Continental Oil Co. Well no. 1, | | |
| Tocito field. Sec. 8, T. 26 N., R. 18 W. | | |
| **Gallup sandstone member and Dilco coal member of Mesaverde formation (Cretaceous** | | |
| Sandstone - - - - - - | 46 | 46 |
| Light-blue shale - - | 7 | 53 |
| Gray sand - - - - - - | 7 | 60 |
| Shale and gray sand | 18 | 78 |
| Gray sand - - - - - - | 7 | 85 |
| Gray shale and sand | 25 | 110 |
| **Lower part of Mancos shale (Cretaceous)** | | |
| Dark-blue shale - - - | 20 | 130 |
| Gray shale - - - - - | 85 | 215 |
| Dark-gray shale - - - | 207 | 422 |
| Lime shell - - - - - | 2 | 424 |
| Gray shale - - - - - | 156 | 580 |
| Gray lime - - - - - - | 8 | 588 |
| Black shale - - - - - | 42 | 630 |
| Dark-gray shale - - - | 90 | 720 |
| Gray shale - - - - - | 104 | 824 |
| Hard shell - - - - - | 2 | 826 |
| Blue shale - - - - - | 14 | 840 |
| Blue shale, bentonite | 30 | 870 |
| Blue shale - - - - - | 10 | 880 |
| **Dakota sandstone (Cretaceous)** | | |
| Fine-grained white water sand - - - - - - - - | 6 | 886 |
| Black shale ("Rainbow" showing) - - - - - - | 1 | 887 |
| Hard gray sand - no increase in water - | 3 | 890 |
| Gray shale - - - - - | 6 | 896 |
| **Morrison formation (Jurassic)** | | |
| Hard sand - - - - - - | 4 | 900 |
| Fine-grained white sand | 7 | 907 |
| Gray sandy shale - - | 3 | 910 |
| Hard sand and shale streaks - - - - - - | 10 | 920 |
| Gray shale - - - - - | 8 | 928 |
| Sand - - - - - - - - | 21 | 949 |
| Dark-gray shale - - | 11 | 960 |
| Sand - - - - - - - - | 10 | 970 |
| Sand with shale - - - | 10 | 980 |
| Sand - - - - - - - - | 15 | 995 |
| Dark shale - - - - - | 13 | 1,008 |
| Coal and shale - - - | 2 | 1,010 |
| **Log of well 12R-84 - Cont.** | | |
| **Morrison formation (Jurassic)-Cont.** | | |
| Coal - - - - - - - - - - | 5 | 1,015 |
| Gray shale - - - - - - | 8 | 1,023 |
| Coal - - - - - - - - - - | 2 | 1,025 |
| Gray shale - - - - - - | 20 | 1,045 |
| Fine-grained gray sand | 35 | 1,080 |
| Lime shell - - - - - - | 2 | 1,082 |
| Gray shale - - - - - - | 6 | 1,088 |
| Shell - - - - - - - - - | 1 | 1,089 |
| Sand - - - - - - - - - - | 1 | 1,090 |
| Light-gray shale - - - | 22 | 1,112 |
| Yellow clay - - - - - - | 5 | 1,117 |
| Hard sand - - - - - - - | 8 | 1,125 |
| Water sand - - - - - - | 5 | 1,130 |
| No record - - - - - - - | 2 | 1,132 |
| Pink shale - - - - - - - | 10 | 1,142 |
| Gray lime shell - - - | 5 | 1,147 |
| Broken lime - - - - - | 3 | 1,150 |
| Hard lime shell - - - | 2 | 1,152 |
| Green shale - - - - - - | 4 | 1,156 |
| Hard lime shell - - - | 2 | 1,158 |
| White shale - - - - - - | 2 | 1,160 |
| Green shale - - - - - - | 5 | 1,165 |
| Red shale - - - - - - - | 5 | 1,170 |
| Gray shale - - - - - - - | 10 | 1,180 |
| Hard sand - - - - - - - | 5 | 1,185 |
| Pink shale - - - - - - - | 7 | 1,192 |
| White shale - - - - - - | 30 | 1,222 |
| Hard sand (water) - - | 2 | 1,224 |
| Light-blue shale - - - | 5 | 1,229 |
| Sand, heavy flow of water | 51 | 1,280 |
| Hard sand - - - - - - - | 5 | 1,285 |
| Gray shale - - - - - - - | 15 | 1,300 |
| Gray sand - - - - - - - | 15 | 1,315 |
| Gray sand with layers of shale - - - - - - - - | 45 | 1,360 |
| Red sand - - - - - - - - | 70 | 1,430 |
| TOTAL DEPTH | | 1,430 |

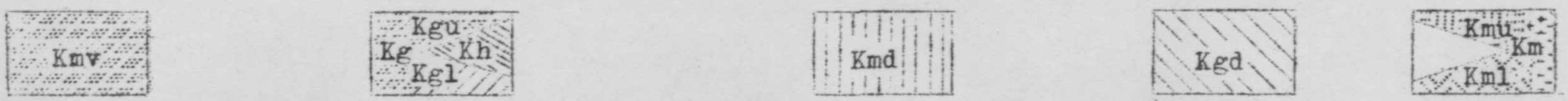
Table 3.-Analyses of water from wells and springs in Banastee area, San Juan County, New Mexico
Analyses by Geological Survey
(Numbers correspond to numbers on plate 1 and in table 1.)
(Parts per million except specific conductance.)

| 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 $CaCO_3$ | Percent Sodium |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12N-25 | Nov. 10, 1948 | 286 | - | 7.4 | 2.4 | 59 | 168 | 11 | 4 | 0.8 | 0.5 | 168 | 28 | 82 |
| 12N-25 | Aug. 6, 1949 | 298 | - | - | - | - | 168 | - | 5 | - | - | - | - | - |
| 12E-83 | Sept. 4, 1949 | 390 | 22 | 2.2 | 1.7 | 92 | 234 | 11 | 5 | .6 | .3 | 250 | 12 | 94 |
| 12E-84 | Aug. 12, 1949 | 422 | 19 | 3.5 | 1.1 | 98 | 236 | 22 | 4 | .6 | .4 | 265 | 13 | 94 |
| S-1 | Aug. 26, 1949 | 1,370 | 23 | 190 | 45 | 69 | 288 | 537 | 10 | .3 | .2 | 1,020 | 659 | 19 |
| S-2 | do. | 1,100 | 14 | 7.5 | 3.1 | 240 | 342 | 239 | 15 | .9 | .2 | 688 | 31 | 94 |
| S-3 | do. | 1,920 | - | - | - | - | 236 | - | 16 | - | - | - | - | - |
| S-5 | Dec. 19, 1949 | 540 | 35 | 34 | 13 | 65 | 72 | 199 | 8 | .7 | .5 | 391 | 138 | 51 |




Explanation

Upper Cretaceous




Mesaverde group in north. Mesaverde formation in south

Gibson coal member of Mesaverde formation, Kg, split northward into an upper part, Kgu, and a lower part, Kgl, by the Hosta sandstone member, Kh, which includes the Satan tongue of Mancos shale.

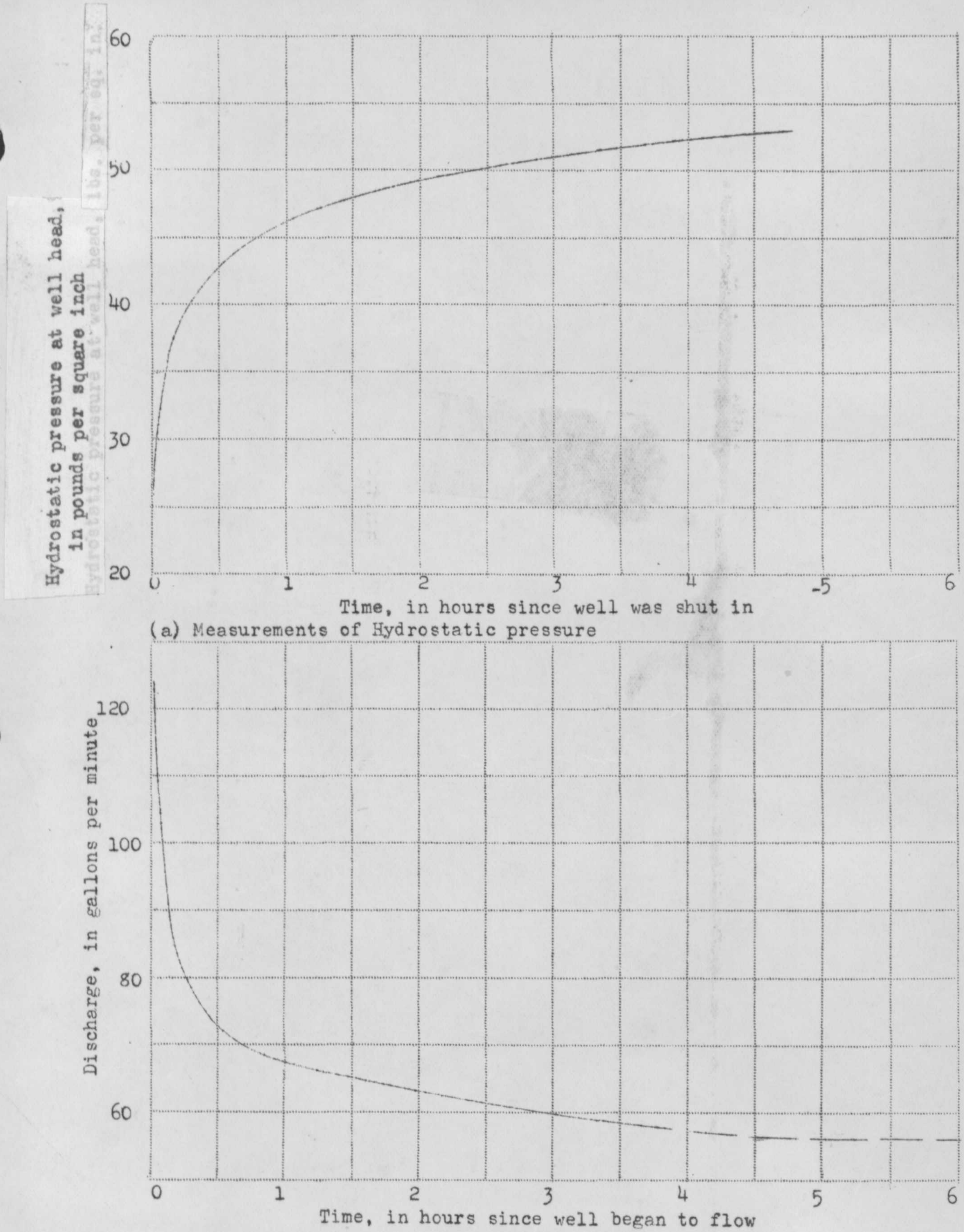
Mulatto tongue of Mancos shale and Dalton sandstone member of Mesaverde

Gallup sandstone and Dilco coal members of Mesaverde

Mancos shale, Km, split southward into an upper part, Kmu, and a lower part, Kml. Km of southmost area equals lower part of Kml farther north.

**Figure 1.** Diagrammatic sketch showing intertonguing relations of units of the Mancos shale and Mesaverde formation.

Adapted from: Pike, W.S., Jr., Intertonguing Marine and Nonmarine Upper Cretaceous Deposits of New Mexico, Arizona, and Southwestern Colorado: Geol. Soc. America Memoir 24, pl. 10, 1947.




(a) Measurements of Hydrostatic pressure

(b.) Measurements of discharge

Figure 2.- Graphs showing results of tests on well 12M-25, Sanastee, N. Mex.