GEOLOGICAL SURVEY CIRCULAR 308

# WATER RESOURCES OF THE CHUSKA MOUNTAINS AREA, NAVAJO INDIAN RESERVATION, ARIZONA AND NEW MEXICO

WITH A SECTION ON QUALITY OF WATER

Prepared in cooperation with the Bureau of Indian Affairs

UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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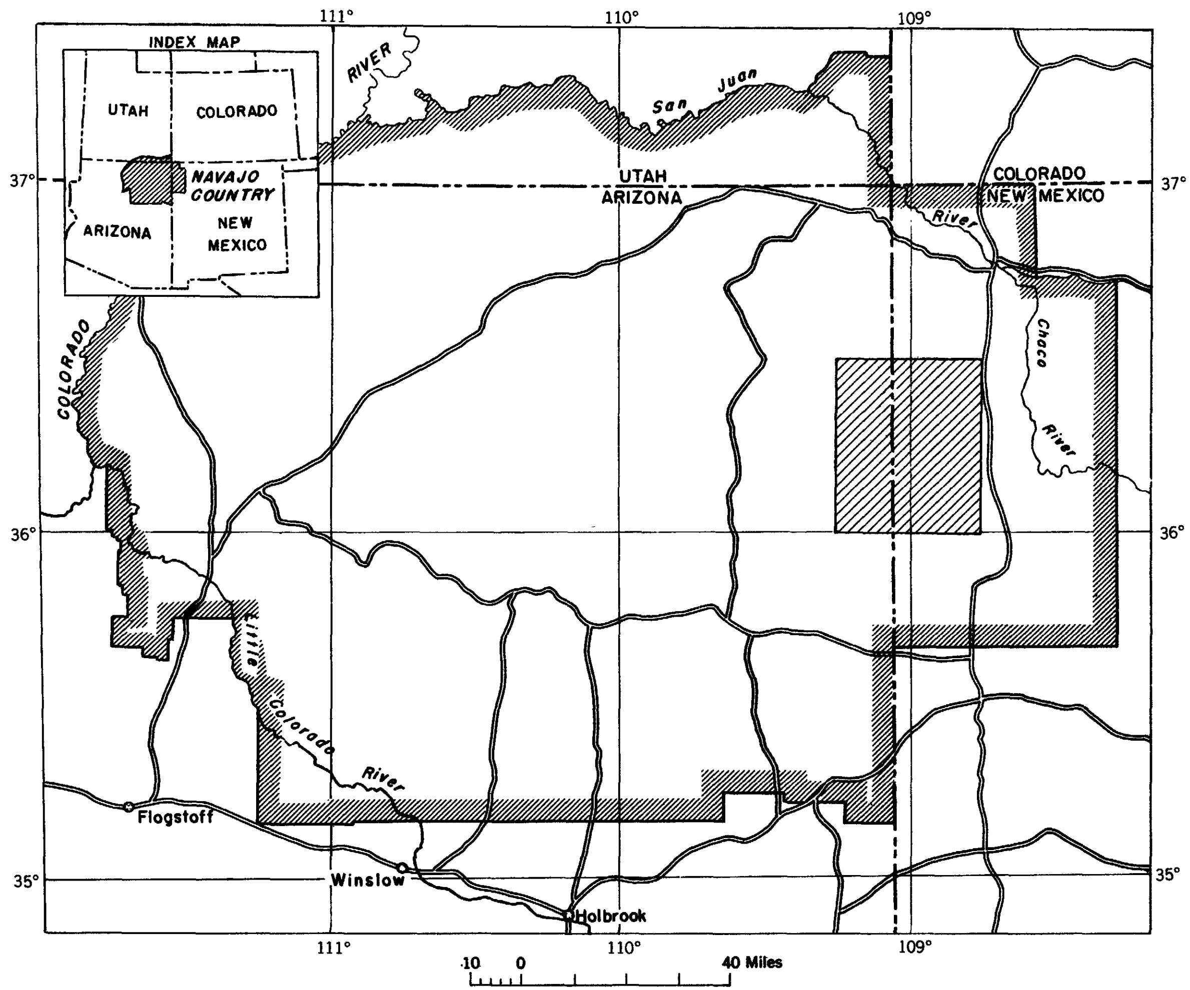


Figure 1. Index map of the Chuska Mountains area, Arizona and New Mexico

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## ABSTRACT

A water-resources investigation was made of the Chuska Mountains area at the request of the Bureau of Indian Affairs to determine the availability of water for the operation of two proposed sawmills and a proposed manganese mill. The daily requirements for the operation of these mills would be more than 220,000 gallons of water of a type suitable for domestic and industrial purposes.

The Chuska Mountains consist of an oblong block of sedimentary rocks, capped by volcanic rocks, that lie on the eastern flank of the Defiance Uplift. In ascending order, the sedimentary rocks that occur in the area are: the DeChelly sandstone of Permian age; the Shinarump conglomerate, Chinle formation, and Wingate sandstone of Triassic age; the Entrada sandstone, Todilto limestone, Summerville formation, and Morrison formation of Jurassic age; the Dakota sandstone, Mancos shale, Gallup sandstone, Point Lookout sandstone, and Menefee formation of Cretaceous age; and the Chuska sandstone of Tertiary age. The water-bearing properties, recharge conditions, and structural attitude of the Chuska sandstone, Morrison formation, Shinarump conglomerate, and the DeChelly sandstone indicate that these formations are favorable for the development of ground-water supplies. The alluvial material in several of the principal drainages also is a potential source of ground-water development.

The available water supplies in the Chuska Mountains area are obtained from both surface-water and ground-water sources. In the western part of the area, there are several principal perennial streams that supply water to local residents for domestic, stock, and irrigation uses. The perennial character of these streams is maintained by ground water discharging from the Chuska sandstone. Numerous springs occur at the base of the Chuska sandstone along the western escarpment because the regional dip of the Chuska is toward the southwest. Ground water can be developed from the Shinarump conglomerate and the DeChelly sandstone anywhere in the western part of the area, but, in the southern part, wells would have to be drilled as deep as 2,000 feet to reach the water-bearing zone. Owing to the closeness of the Defiance plateau, which is the recharge or intake area, the water in the Shinarump conglomerate and in the DeChelly sandstone contains small amounts of dissolved solids and, in general, is of suitable quality.

The streams in the eastern part of the area have an intermittent character, and water supplies are obtained from springs, wells, and surface water. In the higher altitudes, water from runoff and springs is advantageously used for irrigation and domestic purposes. At the lower altitudes, water is obtained from wells that produce from the Cretaceous sandstones and the Morrison formation. In this area, most of the water from the Cretaceous sandstones is not suitable for domestic or industrial purposes; on the other hand, water from the Morrison formation is suitable. The water from the Chuska sandstone contains low amounts of dissolved solids and is suitable for the required uses.

The results of this water-resources investigation indicate that sufficient quantities of suitable water supplies can be developed for the operation of the proposed sawmills and manganese mill. On the western side of the area, at the proposed site for one of the sawmills and the manganese mill, water can be obtained from the perennial streams, from the water-bearing alluvium in Whisky Creek drainage, or from wells penetrating the Shinarump conglomerate and the DeChelly sandstone. On the eastern side, water for the other proposed sawmill can be obtained from a well penetrating the Morrison formation that probably would have an artesian flow.

## INTRODUCTION

An investigation of the water resources of the Chuska Mountains area, Navajo Indian Reservation, Ariz. and N. Mex., was undertaken by the United States Geological Survey during the spring and summer of 1952, at the request of the Bureau of Indian Affairs. The work on the Chuska Mountains area was a part of the regional investigation of the ground-water resources of the Navajo and Hopi Reservations now being made by the Geological Survey. The work was financed by the Bureau of Indian Affairs. The study of the Chuska Mountains area was requested to ascertain the amounts of available water prior to the establishment of two sawmills and a manganese mill in the area.

### Location

The Chuska Mountains area, as discussed in the report, lies in the eastern part of Apache County, Ariz., and in the western part of San Juan County, N. Mex. (fig. 1). The principal communities are Crystal, N. Mex., and Lukachukai, Ariz., about 30 and 90 miles north of Window Rock, Ariz., respectively; and Toadlena and Sanastee, N. Mex., about 80 and 105 miles north of Gallup, N. Mex., respectively. Each of these communities consist of a trading post, a Government school, and the necessary operational personnel.

## Topography and Drainage

The Chuska Mountains are a northwest-trending oblong block of sedimentary formations capped by volcanic rocks (pl. 1). The mountain block is approximately 50 miles long and has an average width of about 2 or 3 miles. The altitude of the mountains is about 9,000 feet. The altitude at Crystal is about 7,400 feet; at Lukachukai, about 6,500 feet; at Toadlena, 6,776 feet; and at Sanastee, 6,400 feet. Crystal and Lukachukai lie at the base of the western escarpment, and Sanastee and Toadlena lie at the base of the eastern escarpment. The western part of the area is a narrow wooded valley lying between the Chuska Mountains and the Defiance Plateau. Within this valley, several prominent buttes are capped by volcanic rocks. Numerous open areas in the valley provide agricultural sites for the local residents. The floor of the valley has an average altitude of 6,500 to 7,000 feet.

The Chuska Mountains block forms a drainage divide between the Chaco River drainage on the east and the Chinle Wash drainage on the west. Because of a gentle southwestward slope of the mountains, there is a greater amount of runoff in the western drainage. The upper tributaries of Chinle Wash are the principal streams along the western side of the mountains. Crystal Creek, Whisky Creek, Wheatfield Creek, and Tsaile Creek all have perennial flow and they join to form Chinle Wash near the mouth of Canyon de Chelly, to the west of the area. The principal drainage channels on the eastern side are intermittent streams, such as: Captain Tom Wash, Theodore Wash, Tocito Wash, and Sanastee Wash. These streams enter the Chaco River, which is an intermittent stream that joins the San Juan River near Shiprock, N. Mex.

## Climate

The Chuska Mountains area lies at a relatively high altitude, and therefore it receives more precipitation than most other areas on the Navajo Reservation. Precipitation and temperature records are sparse and incomplete, but, on the basis of available records, the average annual precipitation is estimated at about 18 inches. Of this amount, about 7 or 8 inches is from snowfall. Owing to the relatively high precipitation, good grazing is prevalent throughout the summer months. However, during the winter months the weather conditions are severe, and because roads in this area are not of the "all-weather" type, parts of the area are inaccessible for as much as 2 or 3 months at a time.

Temporary weather stations are being installed by the Irrigation Branch of the Bureau of Indian Affairs in order to obtain more accurate and more complete records on climatological data. It is expected that the data from these stations will be included in a report on the ground-water resources of the entire Navajo country, now in preparation.

## Summary of Problem

The purpose of this investigation is to determine whether sufficient water supplies could be made available for the operation of the two proposed sawmills and a proposed manganese mill. One of the sawmills is to be constructed either near Whisky Creek or in the vicinity of Wheatfield Creek. The requirement set forth by the Bureau of Indian Affairs for this site states that 100,000 gpd must be available. The other proposed site is on the east side of the mountains in the vicinity of Toadlena, and this requirement calls for 60,000 gpd. It has been estimated that, at each site, about 50 percent of the required water will be for industrial purposes and the other 50 percent will be for domestic purposes. In the middle of the summer of 1952, after the investigation was well under way, information was requested on the possibility of obtaining sufficient water for the operation of a proposed manganese mill in the vicinity of Whisky Creek. It has been estimated that the mill would require 40,000 gpd to treat 1,000 tons of ore per day. The domestic water for operational personnel would, in all probability, require another 20,000 gpd.

The main objective of the investigation was to determine the amounts of water that are available from the streams, or that can be developed from springs and underground water-bearing formations. The potential water supplies from all of these sources are dependent upon a combination of geologic, climatologic, and hydrologic conditions. Therefore, in the discussion of the availability of water, all these conditions must be considered.

## Field Work and Acknowledgments

Field work in the Chuska Mountains area included geologic and hydrologic studies under the immediate supervision of the senior author, and under the general direction of Leonard C. Halpenny, district engineer of the Ground Water Branch for Arizona. Geologic mapping and stratigraphic studies were done by the junior author, who was assisted by James H. Irwin, Maurice E. Cooley, and Peter R. Stevens. Engineering field work and hydrologic studies were done by Robert L. Cushman, who was assisted by William F. Hardt and Albert E. Robinson. The section on Quality of Water was prepared by James L. Hatchett, chemist, Quality of Water Branch.

The writers are greatly indebted to G. B. Keesee, area engineer, and Neal Jennings, hydrographer, Irrigation Branch, Bureau of Indian Affairs, for invaluable assistance and cooperation in regard to climatological data, surface-water measurements, and advice in coordinating hydrologic studies.

# GEOLOGY AND GROUND-WATER RESOURCES

The Chuska Mountains consist of an oblong block of sedimentary rocks capped by basaltic volcanic rocks. Structurally, the mountains lie on the eastern flank of the Defiance uplift—a long, broad anticline which forms Defiance Plateau. The geologic section in this area is as follows:

| | |
|---|---|
| Tertiary system............. | Igneous rock |
| | Chuska sandstone |
| Cretaceous system......... | Mesaverde group |
| | Menefee formation |
| | Point Lookout sandstone |
| | Gallup sandstone |

| | |
|---|---|
| Cretaceous system.......... | Mancos shale |
| | Dakota sandstone |
| Jurassic system.............. | Morrison formation |
| | San Rafael group |
| | Summerville formation |
| | Todilto limestone |
| | Entrada sandstone |
| Triassic system.............. | Wingate sandstone |
| | Chinle formation |
| | Shinarump conglomerate |
| Permian system.............. | DeChelly sandstone |

## Sedimentary Rocks and their Water-Bearing Properties

Cretaceous rocks are present only in the southern and eastern parts of the Chuska Mountains. The Cretaceous formations were eroded from the northern part of the area prior to the deposition of the Tertiary Chuska sandstone. Jurassic and Triassic rocks, in general, are exposed along both flanks of the mountains and consist predominantly of siltstone and silty sandstone. Jurassic rocks have been eroded in the central part of the area. Permian rocks are exposed in only a few areas; they are mostly sandstone that crop out mainly in the western part of the area. The most important water-bearing formations are the Chuska sandstone, which occupies a broad belt in the center of the area, and the DeChelly sandstone.

Two inherent characteristics of rocks that have a large effect upon their capability to hold or transmit water are the degree of sorting and cement. The degree of sorting of a rock is related to the uniformity of grain size within the rock. A poorly sorted rock contains grains of many different sizes, and in this condition smaller grains fill voids between larger grains, thus appreciably reducing the volume of open space available for the movement or storage of water. In a well-sorted rock, the grains are of more or less uniform size, and the voids between the grains remain open, at least until filled with cement. Obviously, the better sorted rocks have greater potentialities as aquifers.

In consolidated rocks, some kind of cement binds the grains together and fills some of the open space between the grains. Naturally, the cement occupying these openings reduces the space normally available for the storage or movement of water. Cement content ranges from practically none in unconsolidated sand to amounts that completely fill the openings between grains in some very dense, hard, and impervious quartzites.

The following discussion gives a more detailed description of the sedimentary rocks, with emphasis upon features pertinent to water-bearing properties. The geologic map, plate 1, shows the location of rock outcrops.

### Permian System

The DeChelly sandstone is the only formation of Permian age exposed in the area of this report.

#### DeChelly sandstone

The DeChelly sandstone is a reddish-orange to very pale orange, fine- to very fine-grained sandstone with grains ranging from 0.12 to 0.06 millimeter in diameter. This relatively clean sandstone forms the massive walls of Canyon de Chelly and has an average thickness of about 700 feet in the area. It crops out in the western part of the area, in the upper reaches of Canyon de Chelly, and in two small canyons at Toadlena. It underlies all the other formations exposed in the area. A suitable domestic water supply could be developed from this sandstone in the vicinity of Whisky Creek.

The DeChelly sandstone is a well-sorted, moderately cemented sandstone, and, although it is a consolidated rock, it is considered to be a good aquifer. However, the cementation of the sandstone is variable, and some parts of the formation are so well cemented that they are essentially impervious to the movement of water.

### Triassic System

The Triassic system comprises three formations in the Chuska Mountains area: the Shinarump conglomerate, the Chinle formation, and the Wingate sandstone of the Glen Canyon group.

#### Shinarump conglomerate

The Shinarump conglomerate is a yellowish-gray, poorly sorted, and moderately to firmly cemented sandstone. It usually contains abundant lenses of consolidated gravel. The Shinarump conglomerate is about 160 feet thick in the Chuska Mountains area. This formation forms the conspicuous cap rock that can be seen in the many canyons in the western part of the area. The Shinarump contains shaly claystone layers that act as impermeable barriers to the movement of ground water. However, these shaly beds are usually lenticular and do not extend laterally for sufficient distances to confine water and produce artesian conditions.

The Shinarump conglomerate is capable of storing fairly large amounts of water in its moderately sorted sandstone and conglomeratic zones. It yields water rather freely to wells in the Defiance Plateau. In the Chuska Mountains area, the Shinarump conglomerate lies directly on top of the DeChelly sandstone, also a relatively good aquifer. Consequently, these two units act as a single aquifer in this area.

#### Chinle formation

The Chinle formation, which overlies the Shinarump conglomerate, is predominantly an impervious claystone. In the Chuska Mountains area, this formation has been divided into three units: a lower sandy unit, the Petrified Forest member, and an upper limy unit.

Lower sandy unit.—The lower sandy unit is lithologically similar to the Shinarump conglomerate, except that it contains more, and larger, units of claystone. However, the unit contains enough conglomeratic sandstone to yield small amounts of water to wells. It is about 225 feet thick in the area and forms low hills and talus-covered slopes capped by sandstone ledges.

Petrified Forest member.—Overlying the lower sandy unit is the most prominent part of the Chinle formation, referred to as the Petrified Forest member by Gregory (1950, p. 67). This member consists of variegated, gray, purple, and red claystones that contain considerable amounts of bentonite. The member forms many painted deserts and contains petrified forests. It is about 450 to 500 feet thick and is impervious to the movement of water; therefore, it acts as a confining layer, causing hydrostatic pressures to be built up in the underlying aquifers—the DeChelly sandstone, the Shinarump conglomerate, and the lower sandy unit of the Chinle formation.

Confining layers are important features in artesian aquifers because they prevent water in the aquifer from moving vertically (thus developing hydrostatic, or artesian, pressure). The penetration of a well into an aquifer beneath a confining layer allows the hydrostatic pressure to force water upward in the well. Flowing wells occur in areas where sufficient hydrostatic pressure is developed to raise the water above the land surface.

A poorly sorted and moderately cemented sandstone, referred to as the "middle sandstone" on plate 1, occurs in the middle of the Petrified Forest member of the Chinle formation. It forms prominent cuestas along the west flank of the Chuska Mountains. This sandstone is considered capable of yielding sufficient water for stock wells. However, the unit is neither thick enough nor permeable enough to yield large amounts of water. Because the sandstone is bounded both above and below by claystones of the Petrified Forest member, in places it contains water under artesian pressure.

Upper limy unit.—The uppermost unit of the Chinle formation contains many thin, siliceous, conglomeratic limestones interbedded with mudstones (Harshbarger, and others, 1951, p. 96). In the Chuska Mountains area, it has an average thickness of about 250 feet and forms a prominent resistant ledge on top of the slopes of the Petrified Forest member. This unit is not capable of yielding water to wells; therefore, it is not considered in the development of water supplies.

Glen Canyon group

To the west of the Chuska Mountains area, the Glen Canyon group comprises several formations that are Triassic and Jurassic in age. Recent work on these sediments has established the presence of a new formation within the group and has led to definite age assignments. The evidence for these changes is presented in a paper by Harshbarger, and others (1954) 1/. It is shown in this paper that the Glen Canyon group consists of four formations: the Wingate sandstone of Late Triassic age, the Moenave formation of Triassic age(?), the Kayenta formation of Jurassic age(?), and the Navajo sandstone of Early Jurassic age. Of these formations, the Wingate sandstone is the only one present in the Chuska Mountains area. It is because of these new age assignments that the Wingate is included in the discussion of the Triassic system.

Wingate sandstone.—The Wingate sandstone is divided into a lower silty member and an upper sandstone member (Harshbarger, and others, 1951, p. 96). In the southern part of the area the Wingate sandstone is represented only by the silty member. This silty member, normally underlying the upper member, is a very fine-grained sandstone that contains considerable siltstone. The sand grains range from 0.12 to 0.06 millimeter; the silt particles, of course, are less than 0.06 millimeter in diameter. This unit nearly always has a moderate reddish-brown color and forms fairly steep crumbly slopes. In the southern part of the area it is about 550 feet thick. In the northern part of the area, where it underlies the vertical cliffs of the upper member, it is about 450 feet thick. Throughout the area it contains tongues and lenses of coarser grained sandstone that is similar to the upper member. These sandstone tongues coalesce with the upper member to the northeast. Because of its impervious character, the lower silty member is not water bearing. Furthermore, it prevents the downward movement of water that occurs in the overlying sandstones.

The upper member of the Wingate sandstone is present only in the northern part of the Chuska Mountains. It is a fine- to very fine-grained, well-sorted sandstone. Its color usually is reddish orange. It is moderately cemented and forms conspicuous massive vertical cliffs. The unit is 300 feet thick in the northern part of the area, near Lukachukai. Because it contains a great amount of fine particles that nearly fill the pore spaces between the sandstone grains, thus reducing permeability, this sandstone unit will yield only small quantities of water to a well.

## Jurassic System

Rocks of Jurassic age in the Chuska Mountains area are classed in two main units: the oldest is the San Rafael group, and the youngest is the Morrison formation.

San Rafael group

In the Chuska Mountains area the San Rafael group is represented by three formations: The Entrada sandstone, the Todilto limestone, and the Summerville formation.

Entrada sandstone.—In the area covered by this report, the Entrada sandstone is represented by two units; the lower one is a reddish-brown, fairly well-sorted siltstone that contains some very fine-grained sand. This lower unit ranges in thickness from 30 to 90 feet and weathers into rounded and knobby outcrops. This unit is not capable of yielding water to wells.

The upper part of the Entrada sandstone is a light-brown to reddish-orange, medium- to fine-grained, moderately well-sorted sandstone. The sand grains range from 0.12 to 0.50 millimeter in diameter. The sandstone is moderately to firmly cemented. The upper unit ranges in thickness from 70 feet in the northern part of the area to 180 feet in the extreme southern part, and it weathers into prominent rounded cliffs throughout the area. The upper part of the Entrada sandstone is capable of yielding water to wells in areas where recharge and structural conditions are favorable

1/ Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., (1954), Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: Manuscript report in files of the U. S. Geol. Survey.

for movement and storage of water. In the western part of the area, the Entrada forms a part of the scarp of the mountains and dips toward the east; the possibilities of developing water in this area are not good. On the east side of the mountains the Entrada yields fairly large quantities of water to flowing wells in the Sanastee area, but the occurrence of oil in this sandstone in this locality renders the water unsuitable for domestic uses.

Todilto limestone.—Immediately above the Entrada sandstone lies the dense, gray, thin-bedded Todilto limestone. The average thickness is about 10 feet. It forms an effective confining layer and is largely responsible for the entrapment of the oil in the upper part of the Entrada sandstone in the Sanastee area. This confining barrier also causes sufficient hydrostatic pressure to force water in the Entrada sandstone to flow from wells in low lands east of the Chuska Mountains.

Summerville formation.—The Summerville formation overlies the Todilto limestone. In this area the Summerville formation is represented by a sandy facies. It consists of moderate reddish-brown, fine-grained, well-sorted, firmly cemented sandstone. It forms cliffs that display the prominent parallel bedding that is characteristic of the Summerville. The formation ranges in thickness from 160 feet in the northern part to 210 feet in the southern part. The Summerville formation yields a limited amount of water to wells in the northeastern part of the area, but it is not considered to be capable of producing adequate supplies for the proposed mills.

### Morrison formation

The Morrison formation comprises four distinct lithologic members in the Chuska Mountains area. These members are approximately correlative to those used by Stokes (1944).

Salt Wash member.—The lowermost member of the Morrison formation is the Salt Wash member, which is present only in the northern part of the area. The Salt Wash member is composed of an alternating sequence of grayish-red to light greenish-gray claystones and of white to moderate-orange sandstones. The sandstones are medium to very fine grained, poorly sorted, and moderately cemented. The member is about 130 feet thick in the vicinity of Sanastee and grades southward into the base of the overlying Recapture member near Toadlena. The Salt Wash member is not present south of Toadlena or Lukachukai.

The Salt Wash is the principal host rock for uranium mineralization in the Morrison formation. The sandstones contain many commercial uranium deposits in the northern end of the Chuska Mountains and in the upper part of Sanastee Wash.

Recapture member.—The Recapture member overlies the Salt Wash member and consists of white and brown weakly cemented sandstones and siltstones. Because of the weakness of the cement, the rock generally weathers into gentle slopes that are covered by soil mantle. Irregularly shaped claystone lenses are common throughout most of the member, thus reducing permeability and retarding the movement of water. In the southern part of the area, a sandy zone at the base of the Recapture member rests upon the Summerville formation. This sandy unit is a tongue of the Cow Springs sandstone (Harshbarger, and others, 1951, p. 97), which is more fully developed south of the Chuska Mountains area. The Recapture member ranges in thickness from 360 feet in the southern part to 470 feet in the northern part of the area. The thickness cited for the southern part includes about 150 feet of the tongue of Cow Springs sandstone.

Westwater Canyon member.—The Westwater Canyon member overlies the Recapture member and consists of pale-green to pale-orange, fine-grained to conglomeratic, poorly sorted and weakly cemented sandstone. This member also contains minor lenticular beds of reddish-brown claystone which do not extend over any great distance laterally. The member usually weathers into blocky cliffs and has an average thickness of about 270 feet in the Chuska Mountains area.

The Salt Wash, Recapture, and Westwater Canyon members of the Morrison formation include the basic features of a relatively good aquifer. The sandstones are fairly well sorted and loosely cemented. The outcrops, as shown in plate 1, provide ample recharge area for infiltration of surface waters. A well drilled in 1951 at the Sanastee school penetrated water-bearing zones in these three members. The beds dip steeply to the east on the eastern side of the mountains, therefore the water is under sufficient hydrostatic pressure to flow from wells. Furthermore, the water obtained from the Morrison formation along the eastern piedmont slope is of suitable quality, partly because of proximity to the recharge area.

Brushy Basin member.—The highest unit of the Morrison formation in the Chuska Mountains area is the Brushy Basin member, which consists of pale-green and gray claystone and thin siliceous limestone. The average thickness in the area is about 120 feet, and the unit weathers into gentle slopes usually covered by talus or soil mantle. The claystone in this member creates an impervious water barrier that prevents the upward movement of water from the lower members.

## Cretaceous System

Rocks of the Cretaceous system in the area of this report are classified into three units: the Dakota sandstone, the Mancos shale, and the Mesaverde group.

### Dakota sandstone

The Dakota sandstone is a pale yellowish-brown, fine- to medium-grained, poorly sorted, firmly cemented sandstone that usually contains a medial, shaly carbonaceous unit. The formation contains coal in many places. The Dakota sandstone ranges from 50 to 150 feet in thickness (there is no apparent regional thickness trend). In some areas the claystone content increases and may be predominant. At present, no satisfactory method of predicting the location of these shaly areas in the Dakota has been developed, and occasionally a well penetrating this formation will not yield water. The Dakota sandstone yields small amounts of water to a number of wells in the Navajo country, but in some areas the quality of the water is unsuitable for domestic and stock purposes.

### Mancos shale

In the Chuska Mountains area the Mancos shale is split into two parts by a sandstone tongue—the Gallup sandstone of the Mesaverde group. The lower part of the Mancos shale is dark-gray fissile claystone, having an average thickness of 750 feet. The upper part is grayish-brown sandy fissile claystone and siltstone, having an average thickness of 950 feet.

The Mancos shale is not an aquifer. The claystone forms a barrier between ground water in the underlying, and overlying, sandstones.

### Mesaverde group

In the Chuska Mountains area the Mesaverde group is represented by the Gallup sandstone, the Point Lookout sandstone, and the Menefee formation.

Gallup sandstone.—The Gallup sandstone occurs as a tongue within the Mancos shale. This tongue is composed of light-gray, fine-grained, thinly bedded sandstone, containing alternating carbonaceous siltstones and scattered coal seams. This formation varies from 60 to 100 feet in thickness. In this area it has been referred to as the Tocito sandstone lentil of the Mancos shale. However, W. S. Pike (1947, p. 28) has correlated this sandstone with the Gallup sandstone to the south of the Chuska Mountains area, and it is so used in this report. The Gallup sandstone has fairly good water-bearing properties. Ground water is capable of moving freely through the sandstone, but the reservoir capacity is not large because of the relative thinness of the formation. Several small springs issue from this sandstone in the vicinity of the Tocito Trading Post, southeast of Sanastee.

Point Lookout sandstone.—The Point Lookout sandstone consists of light-brown, fine- to medium-grained, fairly well-sorted, moderately to firmly cemented sandstone. It is approximately 180 feet thick and forms prominent hogbacks and mesa caps. The Point Lookout sandstone yields a fair amount of water to wells in the San Juan Basin to the east of the Chuska Mountains area. However, because of unfavorable structural attitude there is little possibility of developing large quantities of ground water from the Point Lookout sandstone in this area.

Menefee formation.—The Menefee formation consists of beds of claystone and silty sandstone, most of which are lenticular and not considered to be a suitable source for water in this area. The top of the Menefee is not recognizable in the area, and the total estimated thickness of more than 2,000 feet is believed to contain units equivalent to the Fruitland and Kirtland formations that are located northeast of the Chuska Mountains area.

## Tertiary System

Sedimentary rocks of the Tertiary system in the area consist of one formation—the Chuska sandstone. This formation is confined to the top of the Chuska Mountains and to a few outliers.

### Chuska sandstone

The Chuska sandstone is a white to gray, medium- to fine-grained, moderately sorted sandstone. The lower part contains a moderate amount of silt, which decreases in amount upward and is entirely absent in the upper part of the formation. Occasionally, cementation in the Chuska is quite firm but the larger part of the formation is moderately to weakly cemented (part of this formation contains no noticeable cement). The average thickness of the Chuska sandstone is about 1,000 feet, but this thickness varies according to the nature of deposition and to the degree of recent erosion.

The Chuska sandstone lies at relatively high altitudes and receives large amounts of recharge from rainfall and melting snow. This sandstone is almost completely saturated, but (because it is not confined on the sides) the water discharges from the sandstone as springs. The basal boundary dips about 2° to the southwest, which accounts for the numerous springs on the western side of the mountain area. The streams on the western slope obtain their perennial flow through the discharge of ground water from the Chuska sandstone.

Manganese deposits.—Near the base of the Chuska sandstone, in the area between Whisky Creek and Crystal, there are several small sedimentary manganese deposits. These deposits lie upon an assortment of older formations, ranging in age from the Chinle formation to the Dakota sandstone, at a level approximating that of the pre-Chuska sandstone erosion surface. It is believed that they probably originated as a concentration of manganese precipitates in the vicinity of springs that formerly issued from the base of the Chuska sandstone when the waters were apparently quite heavily charged with soluble manganese salts. Nearly all the deposits contain sands typical of the Chuska, and many of them appear to be Chuska sandstone with a manganese cement. Locally, the Chuska sandstone has a manganese cement, but the main mineralization seems to be in the above-mentioned area. Little is known about the source of the mineral, but manganese cement in the Chuska has been observed in the vicinity of volcanic rocks. The age of the deposits is not definitely established; however, it is known that they are post-Chuska.

## Quaternary System

Unconsolidated material of Quaternary age is common throughout the Chuska Mountains area. Along the eastern escarpment are prominent Quaternary landslide deposits composed mainly of material derived from the Chuska sandstone (which had slumped from the higher parts of the mountain). These landslides cover pre-Quaternary rocks along most of the eastern flank of the mountains. Dune sand is not common in the Chuska Mountains area. Alluvium occurs in most streams and washes and affords reservoir space for limited amounts of ground water.

### Alluvium

The only Quaternary deposits mapped in the area were alluvium that was considered important as a source for water supplies. General mapping of alluvium, or other Quaternary deposits, was not possible because details could not be shown on plate 1.

The alluvium in a few of the washes near the Sanastee School, shown on the map, generally would yield small quantities of water to wells. The material of the alluvium in this area is mainly derived from Cretaceous rocks; consequently it is fine grained and not highly permeable. The water in this alluvium is acceptable for stock, but it contains too much sulfate for domestic use.

Lukachukai, Wheatfield, and Whisky Creeks and Coyote Wash all contain alluvium along their stream courses for short distances. Because of the fact that the alluvium in these drainages is derived primarily from the Chuska sandstone, it is considerably more porous than the alluvium in washes along the eastern escarpment. Therefore, it is logical to assume that much larger quantities of water could be obtained from wells penetrating the alluvium along the western escarpment. Water in the alluvium of these washes is believed to be of good quality.

Considerable care should be used in choosing a site for a well that will produce water from the alluvium along one of the streams of the western escarpment. Because of the limited extent of the alluvium, the choice of well sites should be limited to the areas of thickest strata, thus utilizing as much alluvial mass as possible for storage space. In addition, it would be desirable to locate alluvial wells far upstream in a wash, where the alluvium is more nearly saturated by perennial flow.

## Igneous Rocks and their Water-Bearing Properties

### Tertiary System

In the Chuska Mountains area igneous rocks occur as scattered plugs, dikes, and lava flows. A prominent volcanic vent is present on top of the Chuska Mountains at Washington Pass, and smaller ones occur throughout the area. Minette, tuff, and breccia are the most common igneous rocks; their composition and texture have been fully discussed by Howell Williams (1936). Generally, where both tuffs and lavas are present, deposition of bedded tuffs preceded the eruption of the viscous lavas. Breccias containing angular fragments of lava in a matrix similar to the tuff appear to represent detritus derived from explosive action after some of the viscous lavas had erupted. The final stage of the vulcanism appears to be represented by scoriaceous lava flows that extended over minor areas.

Several springs issue from the volcanic rocks in the area (especially from the breccia and tuff deposits—for example, at the head of Wheatfield Creek). However, the water-bearing properties of the volcanic rocks in the Chuska Mountains area are not important, because only a small amount of the total water discharged from springs in the area are derived from these volcanic rocks.

## Structure

Generally speaking, geologic structural features are a product of pressures within the crust of the earth, which were developed from unstable conditions over long periods of time. These pressures may affect distant parts of the earth's crust, crinkling the rock to relieve the pressures. An upward crinkle, or bend, is termed an "anticline", and a downward bend is termed a "syncline." If the top of one distorted formation were exposed over a wide area, the anticlines would appear as hills and the synclines as valleys.

The attitude of any particular bed at any particular place is shown by its dip and strike. The dip of a bed is the angle at which the bed lies with respect to a horizontal plane. Thus, a horizontal bed has a dip of 0° and a vertical bed has a dip of 90°. The strike of a bed is the bearing of a horizontal line on either the top or the bottom surface of the bed and is measured at right angles to the dip. On a geologic map a symbol ($\lambda$ 3°) is used to indicate the bearing of the strike and the amount and direction of the dip. From these symbols it is possible to interpret the structure involved in the area mapped.

Prior to the deposition of the Chuska sandstone, the older rocks of the area were folded into anticlines and synclines and were then beveled off by erosion to a smooth surface that dips slightly toward the southwest (geologic section, pl. 1). The measurements that were made of the attitude of this surface were consistently $2\frac{1}{2}$° or less, in a southwesterly direction. It is believed that this gentle dip at the base of the Chuska sandstone accounts for the occurrence of the majority of springs and perennial streams on the western side of the mountains. The beveled surface of the older Triassic, Jurassic, and Cretaceous rocks lies underneath the base of the Chuska, and these rocks form a confining layer preventing or impeding the movement of water downward from the Chuska sandstone. When water reaches the base of the Chuska it begins to move laterally (down the dip and toward the western side of the mountains) and issues as springs.

Because the rocks were folded prior to beveling by erosion in pre-Chuska time, formations that are in contact with the base of the Chuska sandstone vary at different localities (pl. 1). This physical relationship to the underlying beds is referred to as an angular unconformity, because the older rocks have a dip that is different from that of the younger rocks. The base of the Chuska sandstone lies upon progressively older rocks from the northern edge of the area southward to a line roughly between Wheatfields Lake and Toadlena. South of this line the Chuska lies on progressively younger formations, until, at the southern edge of the area, it rests almost entirely upon Cretaceous rocks. These conditions have resulted from the beveling of the Defiance uplift and a sharp asymmetrical anticline that lies west of Sanastee and Toadlena (pl. 1). This anticline is entirely covered by the Chuska sandstone, except for its steep eastern side. Between this anticline and the Defiance uplift lies a syncline in the pre-Chuska rocks. This syncline is covered by the Chuska sandstone; however, its presence is indicated by the structural attitude of the pre-Chuska rocks on either side of the mountain.

Other structures in the area include the faulted end of an anticline that extends northward into the area south of Crystal. On the eastern side of the area two anticlines dominate the structure, the Beautiful Mountain anticline and the Tocito dome. These two, and the other structures in the area, trend roughly north and south.

Many of the water-bearing formations do not contain ground water on top of anticlines. The force of gravity encourages the movement of ground water from anticlines into synclines, and, as a general rule, it is more practical to develop ground-water supplies in synclines.

Faults are breaks in the strata, generally caused by forces similar to those that have warped the rocks into anticlines and synclines. In the Chuska Mountains area, faults are not common and have small significance in relationship to the occurrence of ground water. Several faults in the Crystal area resulted from conflicting distortions of minor folds. There are small faults on the eastern side of the mountains, along the strike of the upturned beds. These minor faults trend parallel to the outcrop of the upturned formations and are obscured by the overlying landslide blocks and talus debris. One prominent fault, actually a network of small faults, was observed south of Toadlena where the extreme warping of the strata resulted in rupturing of the rocks.

In some areas, faults may have an important bearing on the occurrence of ground water. For example, an impervious bed may be brought up against an aquifer, thus creating an effective ground-water dam. Or, conversely, a fault may break a confining layer and thus drain a potential artesian aquifer through springs.

## WATER SUPPLIES

### Surface Water

The Chuska Mountains area contains more perennial streams than any other part of the Navajo country. This occurrence is a direct result of the altitude of the area, which receives relatively heavy precipitation. During the dry seasons perennial flow in the streams is maintained by the discharge of ground water from the Chuska sandstone. This sandstone has good aquifer characteristics and is capable of accepting large amounts of water as recharge. The sandstone is geographically and structurally situated in an advantageous position for the maintenance of perennial streams by discharge of ground water. The Chuska sandstone forms the cap rock on the mountains, and therefore it receives direct recharge from precipitation. The relatively flat top of the mountains is spotted with countless small lakes, which act as naturally controlled infiltration areas for recharge to the Chuska sandstone, even in dry seasons. The result of this combination of conditions, unique in the Navajo country, is a permanent and abundant water supply for the many perennial springs and streams in the area.

#### Western-Escarpment Drainage

The most important surface-water drainages of the western escarpment are, from north to south, Lukachukai, Tsaile, Wheatfield, and Whisky (Toh-deth-whith) Creeks and Coyote Wash. With the exception of Lukachukai Creek, all these drainages enter the canyons of Canyon de Chelly National Monument and merge to form Chinle Wash at a point about 10 miles west of the Chuska Mountains area. Lukachukai Creek joins Chinle Wash about 15 miles northwest of the area, near Round Rock Trading Post. Lukachukai Creek is perennial only in the mountainous terrain; its flow is intermittent below Lukachukai, because it is rapidly absorbed by the alluvium in the stream course at the foot of the mountains, or it is diverted from the drainage for irrigation. During the spring months, as is common with all of these drainages along the western escarpment, this wash flows more or less continuously, and in the summer it occasionally carries violent flash floods after heavy rains.

Tsaile Creek is the only drainage that remains perennial throughout its entire course in the Chuska Mountains area. The water flow continues for a considerable distance west of the area, in Canyon del Muerto. It has the largest headwater drainage area, and consequently, it carries the largest flow along the western escarpment. Like the other streams, its point of maximum flow is near the foot of the mountains. This point is usually about a mile downstream from where the stream crosses the lower contact of the Chuska sandstone. Beyond this point, little water is added from tributaries and springs and loss of water is a result of recharge to alluvium and older formations and of dissipation by evapotranspiration.

The point of minimum flow on all streams is where the drainage enters the canyons of Canyon de Chelly National Monument. Upstream from this point the streams have had opportunity to recharge all formations exposed in the area. Although most of the streams are dry at this point during the summer months, they frequently flow below this point because of the added flow of water from springs that occur along the walls of the many deep canyons that breach the DeChelly sandstone. The westerly dip of the Chuska sandstone and the high altitude of the mountains account for the fact that most of the perennial springs and streams of the area are along the western escarpment.

The flow of the main streams along the western escarpment was measured periodically throughout 1952 (table 1). Previous surface-water records of the area were practically nonexistent, and it was hoped that these periodic observations might give some data to estimate the average annual flow and the seasonal variations. The Bureau of Indian Affairs has maintained a gaging station on Whisky Creek since 1948, which has provided records through 1952. Comparing the year 1952 with the 4 preceding years, the following differences in the flow of Whisky Creek were noted: (1) Flow during the spring months of 1952 was approximately five times greater than during the same periods in 1950 and 1951, and it was about equal to that in 1949; (2) flow during the early summer of 1952 was about equal to that of the same time of year in 1950 and 1951, and it was about half of that recorded in 1949; (3) flow in the early fall of 1952 was about half that recorded in 1950 and 1951, and it was only about one-third of the flow recorded in the early fall of 1948 and 1949; (4) flow in the late fall of 1952 was equal to that in 1950 and 1951, and it was about three-fourths of that in 1948 and 1949. During 1950 and 1951, a severe drought occurred in the Southwest. Although there is a lack of precipitation data for this area, rainfall and snowfall were known to be below normal during the drought years, which undoubtedly accounts for the low runoff for these years. In the fall of 1951, and in the winter of 1952, the entire Navajo country received greater amounts of precipitation, which affected the 1952 spring runoff in the area. Weather and runoff data are insufficient to compare

Table 1.—Streamflow measurements in the Chuska Mountains area, 1952

| Stream, and gaging point No. | May | | | June | | | September | | | October | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day of month | Cubic feet per second | Gallons per day (thousands) | Day of month | Cubic feet per second | Gallons per day (thousands) | Day of month | Cubic feet per second | Gallons per day (thousands) | Day of month | Cubic feet per second | Gallons per day (thousands) |
| Coyote Wash | | | | | | | | | | | | |
| 1 | 14 | 5.65 | 3,650 | 6 | 0.68 | 440 | 10 | 0.62 | 399 | 28 | 0.84 | 545 |
| 2 | ..... | ..... | ..... | 6 | 0 | 0 | 10 | 0 | 0 | 28 | 0 | 0 |
| Whisky Creek | | | | | | | | | | | | |
| 3 | 14 | 6.70 | 4,330 | 6 | .88 | 571 | 9 | .55 | 358 | 29 | 1.23 | 797 |
| 4 | ..... | ..... | ..... | ..... | ..... | ..... | 9 | 0 | 0 | 29 | .57 | 370 |
| Wheatfield Creek | | | | | | | | | | | | |
| 5 | 15 | 21.90 | 14,100 | 6 | 1.81 | 1,170 | 10 | 1.49 | 965 | 29 | 2.03 | 1,310 |
| 6 | ..... | ..... | ..... | ..... | ..... | ..... | 10 | 0 | 0 | 29 | 0 | 0 |
| Tsaile Creek | | | | | | | | | | | | |
| 7 | 15 | 25.20 | 16,300 | 6 | 2.99 | 1,930 | 13 | 1.87 | 1,210 | 30 | 2.25 | 1,450 |
| 8 | ..... | ..... | ..... | ..... | ..... | ..... | 13 | .90 | 578 | 30 | 2.59 | 1,680 |
| East tributary of Lukachukai Creek | | | | | | | | | | | | |
| 9 | 15 | 1.97 | 1,270 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Sanastee Wash | | | | | | | | | | | | |
| 10 | 21 | 5.04 | 3,260 | 7 | .53 | 343 | ..... | ..... | ..... | ..... | ..... | ..... |
| Unnamed wash 1 mile south of Toadlena | | | | | | | | | | | | |
| 11 | 17 | 4.08 | 2,830 | 7 | .30 | 194 | ..... | ..... | ..... | ..... | ..... | ..... |

annual averages and thereby determine whether the total streamflow of the Chuska Mountains area in 1952 was above or below average.

### Eastern-Escarpment Drainage

Because of the general westerly drainage slope of the Chuska sandstone, the eastern escarpment is almost devoid of perennial surface streams. A few small creeks are perennial for short distances in their uppermost reaches—notably, Sanastee Wash and a few streams in the vicinity of Toadlena. None of the streams on the eastern escarpment are perennial beyond the break in slope between the mountains and the piedmont surface.

Runoff from melting snow results in flow in the drainage channels for a considerable length of time during the spring months, and these streams supply water for small irrigated plots several miles east of the mountain front. In May 1952, one creek, a few miles south of Toadlena, was flowing at the measured rate of 2.6 cfs, and an additional 1.5 cfs was being diverted for irrigation. Another small creek, 4 miles north of Toadlena, was flowing at the rate of 250 gpm during the same month; all of this water was being diverted for the irrigation of small fields. In the same month, Sanastee Wash was flowing 5.0 cfs at a point about 5½ miles west of the Sanastee School. During the drier parts of the year the flow at all these localities is intermittent.

Perennial springs occur along the eastern flank of the Chuska Mountains, but these springs are not so common nor so large as those along the western escarpment. Springs along the eastern escarpment flowed as much as 60 gpm in 1952. The springs usually occur near the base of the Chuska sandstone, as do those on the western escarpment. Some of the water discharged from the Chuska moves downward beneath landslide material and emerges as springs a considerable distance below the base of the Chuska sandstone. These springs are dependent upon the perennial drainage of the Chuska, rather than upon the intermittent runoff from precipitation therefore they flow at a more or less constant rate throughout the year. The community of Toadlena obtains its domestic water from several springs. Here, the principal spring flowed at a rate of 59 gpm in both April and September 1952. Griggs (1948) 2/ reports that they flowed 95 gpm in January 1948 and 85 gpm in September 1947. The decrease in flow in 1952 could be a result of the intervening drought years. This would suggest that the abnormally low streamflows along the western escarpment during the summer months of 1952 might also be due to past drought years. This condition could be an important factor for the prediction of future flow along the western-escarpment drainages.

The eastern slope of the Chuska Mountains is dotted with small fields, which the Indians irrigate with water from springs. These fields are usually at, or near, the base of the Chuska sandstone, which is the most prominent spring horizon. Springs are also common above this horizon, where local confining layers in the Chuska sandstone cause the water to move laterally to the edge of the mountain. However, these springs are not very important, because they usually occur on steep slopes where the growth of crops is impractical. However, many have been improved and used for stock and domestic purposes. To the east of the mountain slopes—in the low, flat lands—many small fields are concentrated along the intermittent drainage channels where flood runoff is a major source of water for irrigation.

Springs commonly occur also on the top of the Chuska Mountains and are usually associated with volcanic rocks, which act as aquifers in local areas. Some of these springs are quite large and could supply water for limited irrigation if the top of the mountains were frost free and accessible during the growing season. Small natural lakes are common on the top of the mountains and supply water for stock and domestic use. This water is important also for the part it plays in recharging the Chuska sandstone.

2/ Griggs, R. L., 1948, Ground-water resources near Toadlena, N. Mex.: U. S. Geol. Survey open-file report.

## Ground Water

Ground water is available for water supplies throughout the entire area. In the higher altitudes, water could be obtained by development of the springs issuing from the Chuska sandstone. In the lower areas, wells penetrating the underlying sandstone aquifers probably would yield sufficient suitable water for domestic and industrial purposes. Local variation in water-bearing properties, regional distribution, and depth below the land surface, are principal factors for selection of a suitable aquifer to meet water-supply requirements. The DeChelly sandstone and the Shinarump conglomerate are the most promising aquifers for well-water development on the western side of the Chuska Mountains. On the eastern side, the Summerville formation, the Morrison formation, and possibly the Dakota sandstone would yield sufficient suitable water for the proposed installations.

## Present Supplies

### Eastern part of the area

There are several wells in the Sanastee area that produce flowing water from the Jurassic rocks. Well 12M-25 at the Sanastee School has been flowing continuously since 1925. Most of the water is produced from the Morrison formation and the Entrada sandstone. A small amount of oil also issues from the Entrada sandstone, which lies beneath the Todilto limestone. In 1949, tests were made on this well to determine the maximum "shut-in" pressure, the maximum flow, and the physical characteristics of the aquifer. During the first test, the flow from the well was shut off for 4.8 hours. Data obtained from observing the build-up in pressure made it possible to compute the hydrostatic pressure that would have built up if the flow had been cut off indefinitely. This hydrostatic pressure was computed to be 56 pounds per square inch, which is the pressure required to support a column of water 129 feet above the measuring point. The valve was then 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 gpm; thus, the specific capacity of the well was computed to be about 0.45 gpm per foot of drawdown below the computed static head of 129 feet.

In the summer of 1951, a new well was drilled about 1,500 feet northwest of well 12M-25 in an attempt to obtain an oil-free water supply for a proposed school. Unfortunately, the well was drilled to a total depth of 1,475 feet and thereby penetrated 40 feet into the Entrada sandstone (see well log, table 2). Petroleum was encountered in this sandstone, as previously predicted, and it was necessary to plug the hole back to 1,370 feet in order to seal out the undesirable oil contamination. After the cement plug was installed the rate of free flow of water was measured at 42 gpm. A preliminary shut-in pressure of 29 pounds per square inch was recorded. As can be seen in the well log, most of the water from this new well is coming from the sandstones in the Morrison formation. The quality of the water is suitable for domestic and industrial purposes (table 3). Three wells have been drilled on the Tocito dome, in the northeastern part of the area (pl. 1), in search of oil: 12R-83, 12R-83a, and 12R-84 (12R-84 is located north of the first two wells and is outside the area of this report). Two of the three wells were abandoned as possible oil wells and were sold to the Federal Government for use as water wells; the third

Table 2.—Selected drillers' logs of wells in the Chuska Mountains area

Driller's log of well at Sanastee Day School, San Juan County, N. Mex., completed in July 1951; Bureau of Indian Affairs, owner.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| CRETACEOUS: | | |
| Mancos shale (lower part): | | |
| Olive mudstone | 70 | 70 |
| Gray mudstone | 20 | 90 |
| Gray mudstone (water at 150 ft) | 120 | 210 |
| Gray claystone | 80 | 290 |
| Dakota sandstone: | | |
| Gray siltstone | 30 | 320 |
| Gray fine sandstone | 10 | 330 |
| Gray medium sandstone (water) | 40 | 370 |
| JURASSIC: | | |
| Morrison formation: | | |
| Brushy Basin member: | | |
| Gray mndstone | 30 | 400 |
| Gray fine sandstone | 10 | 410 |
| Gray coarse sandstone | 30 | 440 |
| Gray medium sandstone | 10 | 450 |
| Gray fine sandstone | 10 | 460 |
| Gray fine, silty sandstone | 10 | 470 |
| Westwater Canyon member: | | |
| Pink siltstone | 10 | 480 |
| Pink mndstone | 40 | 520 |
| Gray medium sandstone | 30 | 550 |
| Gray mudstone | 10 | 560 |
| Pink medium sandstone | 60 | 620 |
| Purple mudstone | 10 | 630 |
| Pink medium sandstone | 10 | 640 |
| Brown coarse sandstone (water at 690 ft) | 130 | 770 |
| Recapture member: | | |
| Brown medium sandstone | 80 | 850 |
| Brown coarse sandstone (water at 900 ft) | 70 | 920 |
| Brown sandy siltstone | 60 | 980 |
| Red mudstone | 30 | 1,010 |
| Pink fine sandstone | 20 | 1,030 |
| Brown fine sandstone | 60 | 1,090 |
| Brown very fine sandstone | 30 | 1,120 |
| Salt Wash member: | | |
| Pink fine sandstone | 70 | 1,190 |
| Summerville formation: | | |
| Brown fine sandstone (water at 1,200 to 1,240 ft) | 220 | 1,410 |
| Todilto limestone: | | |
| No record (gray limestone and sandstone) | 25 | 1,435 |
| Entrada sandstone: | | |
| Pink medium sandstone (oil at 1,470 to 1,475 ft) | 40 | 1,475 |
| Total depth | | 1,475 |

Casing record:
Cemented 1,475 to 1,445 ft
Sand and gravel fill 1,445 to 1,435 ft
Lead plug, 8 inches by 2 feet, 1,435 to 1,433 ft
Cal seal 1,433 to 1,360 ft
No record 1,360 to 1,098 ft (6 5/8-inch casing?)
8 5/8-inch casing 1,098 to 498 ft (596 ft put in)
10 3/4-inch casing, 498 ft to top (563 ft put in)
(12-inch casing top 12 ft)

Perforations at: 630-690 ft, 900-930 ft, 1,200-1,240 ft.

Driller's log of well at Lukachukai Day School, Apache County, Ariz., completed in September 1951. Bureau of Indian Affairs, owner.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| QUATERNARY: | | |
| Alluvium: | | |
| Gray sand | 30 | 30 |
| TRIASSIC: | | |
| Chinle formation: | | |
| Petrified Forest member (medial sandstone): | | |
| Gray medium sandstone | 10 | 40 |
| Gray coarse sandstone | 10 | 50 |
| Gray medium sandstone | 10 | 60 |
| Gray coarse sandstone (water) | 10 | 70 |
| Petrified Forest member (lower part): | | |
| Purple mudstone | 140 | 210 |
| Gray mudstone | 50 | 260 |
| Red mudstone | 50 | 310 |
| Purple mudstone | 20 | 330 |
| Lower sandy unit: | | |
| Brown coarse to silty sandstone | 10 | 340 |
| Gray coarse to silty sandstone | 10 | 350 |
| Gray very coarse to silty sandstone | 10 | 360 |
| Pink fine sandstone | 40 | 400 |
| Gray fine to silty sandstone (water 440 to 445 ft) | 50 | 450 |
| Gray medium to fine sandstone | 40 | 490 |
| Shinarump conglomerate: | | |
| Gray very coarse to very fine sandstone | 60 | 550 |
| Pink coarse to fine sandstone (water 540 to 550 ft) | 100 | 650 |
| PERMIAN: | | |
| DeChelly sandstone: | | |
| Gray medium to fine sandstone | 40 | 690 |
| Pink medium to fine sandstone | 10 | 700 |
| Orange medium to fine sandstone | 90 | 790 |
| Grayish-orange medium to fine sandstone (water from 820 ft) | 80 | 870 |
| Grayish-orange fine sandstone | 10 | 880 |
| Grayish-orange medium to very fine sandstone | 10 | 890 |
| Grayish-orange fine to very fine sandstone | 10 | 900 |
| Total depth | | 900 |

Casing record:
No record 900 to 486 ft (open hole?)
6 5/8-inch casing 486 to 105 ft
8-inch casing 105 ft to top.

Table 3. –Chemical analyses of surface water of the western Chuska Mountains area, Apache County, Ariz., and San Juan County, N. Mex.

[Analyses in parts per million, except as indicated]

| Stream and gaging point no. | Date of collection | Temperature (°F) | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium and Potassium (Na+K) | Carbonate ($CO_3$) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Hardness as ($CaCO_3$) | Sodium (percent) | Specific conductance (micromhos at 25°C.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Coyote Wash** | | | | | | | | | | | | | | | | |
| 1 | 6- 6-52 | 67 | ... | ... | ... | ... | 7 | 131 | ... | 2 | ... | ... | ... | 112 | ... | 226 |
| 1 | 7- 3-52 | ... | 39 | 44 | 6.9 | 6.9 | ... | 172 | 5.4 | 4 | 0.3 | 0.9 | 192 | 138 | 10 | 287 |
| 1 | 10-28-52 | ... | 29 | 49 | 9.0 | 9.4 | ... | 195 | 12 | 5 | .2 | .3 | 210 | 160 | 11 | 330 |
| 2[1] | 10-29-52 | 33 | 31 | 60 | 12 | 14 | 6 | 238 | 21 | 8 | .4 | .1 | 264 | 199 | 13 | 413 |
| **Whisky Creek** | | | | | | | | | | | | | | | | |
| 3 | 6- 6-52 | 79 | ... | ... | ... | ... | 17 | 158 | ... | 4 | ... | ... | ... | 125 | ... | 260 |
| 3 | 7- 2-52 | ... | 32 | 39 | 9.1 | 14 | ... | 172 | 8.6 | 9 | .2 | 2.2 | 199 | 135 | 18 | 320 |
| 3 | 10-29-52 | 40 | 35 | ... | ... | ... | ... | 200 | ... | 4 | ... | ... | ... | 153 | ... | 323 |
| 4 | 10-29-52 | 62 | 34 | 60 | 18 | 34 | ... | 266 | 45 | 23 | .4 | 0 | 345 | 224 | 25 | 544 |
| **Wheatfield Creek** | | | | | | | | | | | | | | | | |
| 5 | 6- 6-52 | 76 | ... | ... | ... | ... | 15 | 110 | ... | 2 | ... | ... | ... | 93 | ... | 190 |
| 5 | 7- 3-52 | ... | 31 | 32 | 4.9 | 6.7 | ... | 125 | 4.9 | 4 | .3 | .5 | 146 | 100 | 13 | 212 |
| 5 | 10-29-52 | 53 | 40 | ... | ... | ... | 6 | 165 | ... | 2 | ... | ... | ... | 120 | ... | 246 |
| 5 | 10-30-52 | 36 | 38 | ... | ... | ... | ... | 183 | ... | 2 | ... | ... | ... | 139 | ... | 281 |
| 6 | 10-29-52 | 58 | 32 | 49 | 18 | 31 | ... | 253 | 30 | 17 | .4 | .6 | 302 | 196 | 26 | 469 |
| **Tsaile Creek** | | | | | | | | | | | | | | | | |
| 7 | 6- 6-52 | 79 | ... | ... | ... | ... | 11 | 132 | ... | 2 | ... | ... | ... | 111 | ... | 225 |
| 7 | 7- 2-52 | ... | 33 | 42 | 8.0 | 15 | ... | 172 | 6.6 | 15 | .3 | 1.1 | 206 | 138 | 19 | 332 |
| 7 | 10-30-52 | 43 | 34 | ... | ... | ... | ... | 195 | ... | 2 | ... | ... | ... | 150 | ... | 301 |
| 8 | 10-30-52 | 50 | 33 | ... | ... | ... | ... | 204 | ... | 4 | ... | ... | ... | 160 | ... | 337 |

[1]Stream was below sampling point.

well, 12R-83a, was capped. The discharge and maximum hydrostatic pressure of wells 12R-83 and 12R-84 were measured in the late summer of 1949. The openflow rate of discharge of well 12R-83 was 19 gpm. The computed hydrostatic pressure at the end of 3 hours "shut-in" was 16 pounds per square inch. The openflow rate of discharge of well 12R-84 was 11 gpm, and the computed hydrostatic pressure at the end of 3 hours of "shut-in" was 15 pounds per square inch. A study of the driller's logs indicates that, for the most part, the water comes from the sandstones of the Morrison and Summerville formations.

There are several shallow wells in this eastern part of the area that produce small amounts of water, some from the Gallup sandstone and some from the alluvium. The water from these shallow wells is unpalatable and is probably unsuitable for domestic or industrial purposes. The possibility of developing adequate water supplies for the proposed installations from these shallow wells is remote and will not be given further consideration in this report.

Favorable geologic and hydrologic data collected at the proposed sawmill location about 2 miles northeast

Table 4.—Stratigraphic section that would be encountered by drilling a well 2 miles northeast of Toadlena, N. Mex.

| Formation | System | Water-bearing character | Thickness (feet) | Depth to base of formation (feet) |
|---|---|---|---|---|
| Alluvium: | Quaternary | Non-water-bearing | 20-30 | 20-30 |
| Mancos shale: Upper part: (Greenish-gray shale) | Cretaceous. | Non-water-bearing | 500-600 | 520-630 |
| Gallup sandstone: (Light-gray sandstone) | Cretaceous | Water-bearing | 60 | 580-690 |
| Mancos shale: Lower part: (Olive-gray shale) | Cretaceous. | Non-water-bearing | 800 | 1,380-1,490 |
| Dakota sandstone: (Light-gray sandstone) | Cretaceous | Water-bearing | 180 | 1,560-1,670 |
| Morrison formation: (Brown, gray, and pink sandstone and shale) | Jurassic | Water-bearing in lower parts | 830 | 2,390-2,500 |
| Summerville formation: (Light-brown sandstone) | Jurassic | Water-bearing | 270 | 2,660-2,770 |
| Todilto limestone: (Dense gray limestone) | Jurassic | Non-water-bearing | 13 | 2,673-2,783 |
| Entrada sandstone: (Gray and pink sandstone) | Jurassic | Water-bearing; oil possible | 180 | 2,853-2,963 |
| Wingate sandstone: Lower member: (Reddish-brown siltstone) | Triassic. | Non-water-bearing | 450 | 3,303-3,413 |
| Chinle formation: (Red-gray and blue shales and sandstone) | Triassic | Non-water-bearing | 975 | 4,278-4,388 |
| Shinarump conglomerate: (Gray sandstone) | Triassic | Water-bearing | 160 | 4,438-4,548 |
| DeChelly sandstone: (Pale-orange sandstone) | Permian | Water-bearing | 400 | 4,838-4,948 |

of Toadlena indicate that a flowing well could be developed here. The well probably would have a free-flow rate of about 40 gpm, and the quality of the water would probably be comparable to that produced from the new well at the Sanastee School. However, to obtain production from the Morrison and Summerville formations, a well about 2,700 feet deep would be required. A stratigraphic section in table 4 shows the type of rocks that would be encountered and their corresponding thicknesses.

As mentioned above, there are a number of small springs at the base of the Chuska sandstone. These springs are near the top of the eastern side of the mountain, and their yield is comparatively small in comparison with that of the springs on the western escarpment. Because of limited yield, inaccessibility, and the fact that essentially all the water is utilized for local irrigation, stock, and domestic purposes, these springs are not considered to be favorable sources for a water supply for the proposed Toadlena sawmill.

The Toadlena springs (S-19 and S-20) are located about a quarter of a mile northwest of that community. The water issues from the DeChelly sandstone and is used to supply the water required for the various installations at Toadlena. Periodic measurements of the flow of these springs since 1948 show an average flow of about 80 gpm. The quality of the water is good (table 5) and is used for domestic purposes. During the drought years (1950 and 1951), the flow decreased to about 94 percent of the average flow. The water produced by the Toadlena springs is utilized by the local residents, and an increase in population may necessitate the development of additional water supplies. Therefore, it is unlikely that water from these springs could be diverted readily to supply the requirements of the proposed sawmill. Several more small springs in the vicinity of Toadlena yield small quantities of water from the alluvium; however, the flow is small and is dependent upon the amount of precipitation that may occur in the area.

### Western part of the area

The principal sources of ground-water supplies in the western part of the area are the DeChelly sandstone, the Shinarump conglomerate, the Chuska sandstone, and the alluvium in the main stream courses. Small quantities of water could be obtained from the thicker sandstones in the Chinle formation, the Summerville formation, or the Entrada sandstone. However, it is believed that production from these three formations would be insufficient to meet the water requirements prescribed.

Because of the relative abundance of perennial water supplies from springs and streams, there are only a few producing wells in this part of the area. The wells in the area, and those in adjacent areas to the west, produce water from the Shinarump conglomerate, the DeChelly sandstone, and alluvium. The most significant of these wells (at the Lukachukai Day School) was drilled in the latter part of 1951 to a total depth of 900 feet (well log, table 2). The well penetrated 490 feet of the Chinle formation, 160 feet of the Shinarump conglomerate, and 250 feet of the DeChelly sandstone. Water was encountered in both the Shinarump conglomerate and the DeChelly sandstone. A preliminary bailing test was made upon completion of the well in September 1951. The static water level was 431 feet below the surface, and the well was bailed at the rate of 14.8 gpm for 63 minutes. The drawdown during this time was 51 feet below the static level. There was no pumping equipment at the well, therefore it was not possible to compute the specific capacity of the well. However, it is assumed that the well probably would yield 15,000 gpd.

There are several other wells to the west of the Chuska Mountains area that produce water from the DeChelly sandstone. Well 11Y-109, located about 6 miles west of Lukachukai, was drilled to a total depth of 500 feet in 1939. The surface at the well site is near the top of the Shinarump conglomerate, and the well penetrates approximately 350 feet of DeChelly. The static water level is reported to be 179 feet below the surface of the ground, and a bailing test produced 15 gpm with a resultant drawdown of 195 feet. The main water-bearing zone is between 455 and 465 feet below the surface. Another well, 11T-235, located about 7 miles southwest of Lukachukai, was completed in September 1951. This well, drilled to a total depth of 470 feet, penetrated 110 feet of the Shinarump conglomerate and 360 feet of the DeChelly sandstone. The main water-bearing zone lies between 430 and 440 feet below the surface. According to the results of a preliminary bailing test, the well is capable of yielding about 10,000 gpd.

Geologic and hydrologic conditions indicate that it would be feasible to develop ground water by drilling wells at the proposed sawmill sites at Whisky Creek or Wheatfield Creek. It would be necessary to penetrate the DeChelly sandstone to a depth of at least 300 feet in order to obtain the maximum yield. The DeChelly crops out on the Defiance uplift to the west at an altitude that is higher than that of the proposed sawmill sites, thus affording good recharge conditions. The strata dip eastward from the outcrop and permit eastward movement of ground water from the top of the uplift (see geologic section, pl. 1). The proposed sites are near the bottom part of a shallow synclinal structure, and the DeChelly sandstone and the Shinarump conglomerate are likely to be saturated at this point. Table 6 shows the probable stratigraphic section that would be encountered in the vicinity of the Whisky Creek site. The amount of water that could be produced from a single well is unknown, but because of more favorable structural and recharge conditions it is believed that the aquifers in this locality are capable of yielding more water than those at the Lukachukai Day School. It is estimated that a well would produce about 25,000 gpd. There would be some artesian rise, but the well probably would not flow. Consideration of analyses of similarly located wells (given in table 4) leads to the assumption that the water probably would be suitable for domestic and industrial purposes.

In the southwestern part of the area there are no significant wells producing water supplies. Water for local use is obtained from springs, from perennial streams, and from a few shallow wells dug in the alluvium. The areas in which alluvium affords the best possibilities of developing adequate water supplies are along the main streams. From south to north, these streams are: Coyote Wash, Whisky Creek, Wheatfield Creek, and Tsaile Creek. In general, the lower parts of the streams have a flatter stream gradient and, conse-

Table 5.—Chemical analyses of ground water in the Chuska Mountains area, Apache County, Ariz., and San Juan County, N. Mex.

[Analyses in parts per million, except as indicated]

| Stream and gaging point no. | Date of collection | Temperature (F) | Silica ($SiO_2$) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium (NaK) | Carbonate ($CO_3$) | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Hardness as ($CaCO_3$) | Sodium (percent) | Specific conductance (micromhos at 25°C.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quaternary system: | | | | | | | | | | | | | | | | |
| 12-R-93A | 11-10-48 | 58 | ...... | 1.0 | 1.2 | 111 | 9 | 226 | 45 | 10 | 0.4 | 0.6 | 280 | 8 | 97 | 471 |
| S-1 | 9-15-49 | 62 | 40 | 239 | 130 | 216 | ...... | 246 | 1,260 | 61 | .4 | .2 | 2,070 | 1,130 | 29 | 2,510 |
| S-2 | 8-26-49 | ...... | 14 | 7.5 | 3.1 | 240 | 34 | 342 | 239 | 15 | .9 | .2 | 688 | 31 | 94 | 1,100 |
| S-3 | 8-26-49 | ...... | 28 | 190 | 45 | 69 | ...... | 288 | 537 | 10 | .3 | .2 | 1,020 | 659 | 19 | 1,370 |
| S-4 | 8-26-49 | ...... | ...... | ...... | ...... | ...... | ...... | 236 | ...... | 16 | ...... | ...... | ...... | ...... | ...... | 1,920 |
| W-1 | 6-27-48 | 53 | 49 | 56 | 31 | 118 | ...... | 482 | 56 | 46 | 0 | 5.7 | 599 | 267 | 49 | 925 |
| 12K-400A | 11-18-48 | 47 | ...... | 153 | 43 | 176 | ...... | 255 | 662 | 28 | .6 | 2.8 | 1,190 | 558 | 41 | 1,640 |
| S-5 | 10-16-50 | 60 | 33 | 156 | 66 | 76 | ...... | 512 | 363 | 19 | .7 | .3 | 966 | 660 | 20 | 1,370 |
| Tertiary system: | | | | | | | | | | | | | | | | |
| S-6 | 6-27-48 | 63 | 43 | 51 | 9.7 | 14 | 9 | 217 | 11 | 5 | 0 | .9 | 242 | 167 | 15 | 340 |
| S-7 | 8-25-48 | ...... | ...... | ...... | ...... | ...... | ...... | 255 | ...... | 3 | ...... | ...... | ...... | ...... | ...... | 403 |
| S-8 | 9-11-52 | 58 | 37 | 38 | 6.8 | 2.1 | ...... | 141 | 4.7 | 2 | .2 | 4.1 | 164 | 123 | 4 | 246 |
| S-9 | 8-28-50 | 48 | ...... | ...... | ...... | ...... | ...... | 56 | ...... | 3 | ...... | ...... | ...... | ...... | ...... | 111 |
| S-10 | 9- 4-52 | 48 | 41 | 52 | 11 | 3.4 | 5 | 211 | 2.7 | 4 | .2 | .3 | 219 | 174 | 4 | 328 |
| S-11 | 9-15-52 | 55 | ...... | ...... | ...... | ...... | ...... | 154 | ...... | 4 | ...... | ...... | ...... | ...... | ...... | 250 |
| Cretaceous system: | | | | | | | | | | | | | | | | |
| Sanastee | 6- 6-51 | ...... | 9.8 | 20 | 2.0 | 303 | ...... | 525 | 253 | 15 | .8 | .2 | 863 | 58 | 92 | 1,060 |
| S-12 | 9-17-52 | 60 | 28 | 138 | 35 | 32 | ...... | 310 | 270 | 15 | .6 | 1.1 | 672 | 488 | 13 | 940 |
| S-13 | 9-16-49 | 62 | 42 | 96 | 26 | 28 | ...... | 302 | 91 | 41 | .1 | 8.1 | 481 | 346 | 15 | 731 |
| S-15 | 10-16-50 | 59 | 24 | 278 | 83 | 57 | ...... | 388 | 784 | 16 | .7 | .4 | 1,430 | 1,040 | 11 | 1,780 |
| Naschitti[1] | 5-26-51 | 62 | 14 | 8.0 | 2.6 | 182 | 12 | 445 | 47 | 5 | 1.6 | .5 | 480 | 30 | 93 | 725 |
| 12R-98[1] | 12-15-48 | 50 | ...... | 19 | 14 | 299 | ...... | 342 | 440 | 11 | .6 | 1.4 | 954 | 105 | 86 | 1,400 |
| 12R-100[1] | 8- 9-49 | 60 | 22 | 34 | 24 | 268 | ...... | 286 | 481 | 21 | .5 | .3 | 992 | 184 | 76 | 1,450 |
| Jurassic system: | | | | | | | | | | | | | | | | |
| 12R-84[1] | 8-12-49 | 76 | 19 | 3.5 | 1.1 | 98 | 26 | 236 | 22 | 4 | .6 | .4 | 265 | 13 | 94 | 422 |
| 12R-83 | 9- 4-49 | 77 | 22 | 2.2 | 1.7 | 92 | 30 | 234 | 11 | 5 | .6 | .3 | 250 | 12 | 94 | 390 |
| Sanastee | 6-28-51 | 70 | 14 | 7.0 | 2.4 | 137 | 15 | 290 | 67 | 11 | .4 | .8 | 383 | 28 | 92 | 632 |
| 12-M-25 | 11-10-48 | 68 | ...... | 7.4 | 2.4 | 59 | ...... | 168 | 11 | 4 | .8 | .5 | 168 | 28 | 82 | 286 |
| Triassic system: | | | | | | | | | | | | | | | | |
| S-16 | 6-23-48 | 59 | ...... | ...... | ...... | ...... | ...... | 496 | ...... | 35 | ...... | ...... | ...... | ...... | ...... | 1,070 |
| S-17 | 7-29-49 | 55 | ...... | ...... | ...... | ...... | ...... | 500 | ...... | 54 | ...... | ...... | ...... | ...... | ...... | 991 |
| S-18 | 8- 2-49 | 60 | ...... | 34 | 34 | 136 | ...... | 468 | 98 | 24 | .4 | .6 | 558 | 225 | 57 | 919 |
| Permian system: | | | | | | | | | | | | | | | | |
| Lukachukai | 9-24-51 | ...... | 10 | 10 | 7.5 | 140 | ...... | 343 | 59 | 11 | .6 | 1.0 | 408 | 56 | 84 | 669 |
| 11Y-109[1] | 2-49 | ...... | ...... | 121 | 39 | 28 | ...... | 346 | 216 | 8 | .7 | .6 | 584 | 462 | 11 | 894 |
| S-19 | 8-24-48 | 56 | ...... | 27 | 9.5 | 14 | ...... | 150 | 10 | 3 | .2 | .2 | 138 | 106 | 23 | 251 |
| S-20 | 8-25-48 | ...... | ...... | 68 | 13 | 23 | 16 | 302 | 9.3 | 11 | .6 | .2 | 274 | 223 | 19 | 481 |

[1]Out of Chuska Mountains area.

Table 6.—Stratigraphic section that would be encountered by drilling a well 1 mile northwest of Whisky Creek bridge.

| Formation | System | Water-bearing character | Thickness (feet) | Depth to base of formation (feet) |
|---|---|---|---|---|
| Alluvium: | Quaternary | Non-water-bearing | 10-20 | 10-20 |
| Chinle formation: | Triassic | | | |
| Upper limy unit: (red shale and limestone) | | Non-water-bearing | 150-200 | 160-220 |
| Petrified Forest member: (blue and gray shale) | | Non-water-bearing | 450-500 | 610-770 |
| Lower sandy unit: (gray sandstone and red shale) | | Water-bearing | 225 | 835-995 |
| Shinarump conglomerate: (gray sandstone) | Triassic | Water-bearing | 160 | 995-1,155 |
| DeChelly sandstone: (pale-orange sandstone) | Permian | Water-bearing | 600-700 | 1,595-1,855 |

quently, 20 to 30 feet of sandy alluvial material has accumulated. Most of these potential water-bearing areas, shown on the map (pl. 1), lie west of the main road that traverses the western side of the area. No wells have been developed in the alluvial aquifers; however, the authors believe that several test holes would be warranted in order to obtain quantitative data on the amount and quality of water that the alluvium is capable of yielding. It is believed that wells of the caisson type in certain parts of the alluvium would produce 20,000 to 30,000 gpd. However, judicious selection of well sites would result in maximum sustained yield.

As mentioned previously, there are a number of springs that issue from the base of the Chuska sandstone along the western escarpment of the mountains. The points of emergence are shown on the map (pl. 1) by a spring symbol; numbers have been assigned to only a few of the springs. The water from the springs enters the headward drainage of Coyote Wash, Whisky Creek, Wheatfield Creek, and Tsaile Creek. Gaging points were selected along these streams to ascertain the amount of flow from the springs. The measurements obtained at the upper gaging points, during a period of no appreciable surface water runoff from precipitation, represent water produced by the springs (table 1). A total of 4.5 cfs in the four major drainages probably represents the measurable production from the springs. Owing to the natural losses between points of emergence and the measuring points, this amount of water represents the minimum spring production. The gaging points farther downstream were used to determine the gain or loss of water between points. Table 1 shows that the lower parts of the streams are dry. The loss of water is attributed to one or more of the following factors: (1) evapotranspiration; (2) recharge to the sandy alluvium and DeChelly sandstone in the lowermost parts of the streams; or (3) diversion for local irrigation purposes. Although no specific data could be obtained, it is believed that a large part of this loss is recharged to the alluvium and DeChelly sandstone in the stream courses.

The authors believe that it is possible to develop a sufficient amount of water from the springs that issue from the base of the Chuska sandstone. Undoubtedly, a considerable amount of water is dissipated by natural losses and does not enter the major drainages. Catchment areas could be constructed for the collection of spring discharge. However, it would be necessary to construct pipelines or open ditches to transport the water to the proposed installations. Because of the fact that perennial flow in the major streams is maintained by discharge from springs, sufficient water could be diverted from any one of these streams near the proposed installation. However, it may be necessary to make arrangements with the local residents for apportionment of the water during the crop-growing season to insure sufficient water for irrigation use. The quality of the water in these streams was analyzed and the results are shown in table 3. It is believed that the water is suitable for domestic and industrial purposes.

## Quality of Water, by J. L. Hatchett

### Surface Water

A general indication of the quality of surface water in the Chuska Mountains area is given by analyses of 17 spot samples (table 3). The quality of water of the streams at low flow is similar to that of springs issuing from the rocks of Tertiary age, but during times of runoff resulting from rain and melting snow the streams probably carry water of lower dissolved-solids concentration. The analyses show that the water from streams in the Chuska Mountains area contained more dissolved solids in October 1952 than in June and July of the same year. The dissolved-solids concentration of water at the downstream gaging points was generally higher than at the upstream gaging points. The hardness of the water also followed the same pattern—highest in early fall, and highest at the downstream gaging points.

A sample from Whisky Creek, collected on October 29, 1952, had a dissolved-solids content of 345 ppm, which was the highest of the waters sampled. Water from Wheatfield Creek on June 6, 1952, had the lowest dissolved-solids content, which was approximately 120 ppm. The highest figure for hardness was 224 ppm for water collected from Whisky Creek on October 29, 1952, and the lowest figure was 93 ppm for water collected from Wheatfield Creek on June 6, 1952. The silica content of the water ranged from 29 to 42 ppm. The range in temperature of the water was from 33° to 79° F. The predominant cation of the water from the streams was calcium and the predominant anion was bicarbonate. Silica concentrations were rather high in all the waters and usually amounted to more than 10 percent of the dissolved solids.

### Ground Water

Analyses of water from wells and springs that were sampled in the Chuska Mountains area are shown in table 5. Analyses of water from wells and springs adjoining the area of this report were considered, and some of these analyses are included in the table.

An analysis of water from the DeChelly sandstone and the overlying Shinarump conglomerate at the Lukachukai Day School shows that the water contained 408 ppm of dissolved solids, 10 ppm of silica, and had a hardness of 56 ppm. The predominant cation of this water was sodium, and the predominant anion was bicarbonate. Well 11Y-109, located about 6 miles west of the day school, is closer to the recharge area. The water from this well had a dissolved-solids content of 584 ppm and a hardness of 462 ppm. The principal cation was calcium, and the principal anion was bicarbonate. Consideration of analyses of other wells west of Lukachukai indicate that the water may be softened as it moves through these formations. The geologic section, plate 1, shows that the strata dip in such a manner that the ground water in these formations is probably moving eastward in this area.

A sample from the Chinle formation (S-18) near Lukachukai had a dissolved-solids content of 558 ppm. The principal constituents were sodium and bicarbonate.

In the Sanastee area, water from Jurassic rocks was soft, had a dissolved-solids content of less than 400 ppm, and had a silica content of approximately 20 ppm.

Water from Cretaceous rocks in the Chuska Mountains area was variable in quality. Sulfate was the principal anion in water from spring S-15, and calcium was the principal cation. Sodium and bicarbonate were the important dissolved constituents in the water derived from Cretaceous rocks during the development of the well drilled in 1951 at the Sanastee Day School. The hardness of the eight samples of water collected from Cretaceous rocks ranged from 30 to 1,040 ppm, and the dissolved-solids content ranged from 391 to 1,430 ppm.

Rocks of Tertiary age in the Chuska Mountains area yielded water containing less than 300 ppm of dissolved solids. Hardness ranged from 123 to 174 ppm for three samples. Calcium, bicarbonate, and silica were the principal constituents of the dissolved solids. The silica content was approximately 40 ppm.

Alluvial material is derived from rocks of many ages and types, therefore the quality of water in the alluvium varies. The quality of water in the alluvium is affected also by evapotranspiration. Well 12K-440A, near the Two Gray Hills Trading Post, yielded water that contained calcium and sodium as the principal cations and sulfate as the principal anion. Sodium was the principal cation and bicarbonate was the principal anion in water from well 12R-93A, south of the Tocito Trading Post. The hardness of eight samples of water from alluvium ranged from 8 to 1,130 ppm, the silica content ranged from 14 to 49 ppm, and the dissolved-solids content ranged from 280 to 2,070 ppm.

The temperature of ground water below depths of a few tens of feet is almost constant throughout the year, but the temperature of small surface streams (table 3) fluctuates considerably. Variation in temperature of the water, as well as variation in chemical quality, should be considered in a determination of a desirable water supply for industrial purposes.

Water derived from the DeChelly sandstone and the Shinarump conglomerate, in the area near Whisky Creek and Wheatfield Creek, and water from these creeks, should be of satisfactory quality for domestic use and for most industrial purposes. Jurassic rocks, in the area near Toadlena, should yield water of satisfactory quality for domestic use and for most industrial purposes.

## CONCLUSIONS

The results of this investigation on the water resources of the Chuska Mountains area indicate that sufficient water can be obtained for the proposed sawmill sites and manganese mill. Conditions for developing water supplies in the vicinity of Whisky Creek are as follows:

1. About 100,000 gpd of potable water will be needed for the proposed sawmill, and 40,000 gpd will be needed for the proposed manganese mill.

2. Results of measurements of the surface water in Whisky Creek indicate that the minimum perennial flow is slightly over $\frac{1}{2}$ cfs, or approximately 360,000 gpd.

3. If adequate storage facilities are constructed, sufficient water could be diverted for both industrial installations without seriously interfering with local irrigation requirements.

4. Water supplies could be developed by drilling wells into the underlying Shinarump conglomerate and DeChelly sandstone. The required drilling depth would be about 1,400 feet, thus allowing for sufficient penetration into the water-bearing sandstone. It is estimated that a single well would be capable of yielding about 25,000 gpd. Six wells, spaced not less than 1,500 feet apart, would produce enough water for the industrial installations.

5. It is suggested that test holes be drilled into the alluvium to determine the amount and quality of water. It is estimated that caisson-type wells may produce 20,000 to 30,000 gpd.

6. Sufficient water supplies could be obtained by developing the springs that issue from the base of the Chuska sandstone. Water from this source would be of the best quality obtainable in the area. However, several miles of transmission facilities would have to be constructed to deliver the water to the proposed installations.

Conditions for the development of water supplies for the proposed sawmill northeast of Toadlena, N. Mex., are as follows:

1. About 60,000 gpd of suitable water will be needed to meet the water requirements.

2. Because of meager and intermittent flow, and because of prior appropriation of much of the water, the streams and springs in the immediate area are not considered capable of development.

3. A well, drilled about $2\frac{1}{2}$ miles northeast of Toadlena to penetrate the underlying Morrison and Summerville formations, would yield about 60,000 gpd. Geo-

logic structural conditions encourage the belief that the well would produce at a free-flow rate of about 40 gpm. However, a total well depth of about 2,700 feet would be necessary to allow sufficient penetration into the water-bearing rocks. On the basis of analyses of water from the Sanastee School well, the water is expected to be of suitable quality for domestic and industrial purposes.

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