Availability and Quality of Ground Water, Southern Ute Indian Reservation, Southwestern Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1576-J

Prepared in cooperation with the Southern Ute Tribal Council, the Four Corners Regional Planning Commission, and the U.S. Bureau of Indian Affairs

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By ROBERT E. BROGDEN, E. CARTER HUTCHINSON, *and*
DONALD E. HILLIER

WATER SUPPLY OF INDIAN RESERVATIONS

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CONVERSION FACTORS

[For the use of those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below]

Multiply English unit	*By*	*To obtain metric unit*
inches (in.)	25.40	millimeters
feet (ft)	.3048	meters
miles (mi)	1.609	kilometers
square miles (mi^2)	2.590	square kilometers
gallons per minute (gal/min)	.06309	liters per second
parts per million (ppm)	1.000	milligrams per kilogram

AVAILABILITY AND QUALITY OF GROUND WATER, SOUTHERN UTE INDIAN RESERVATION, SOUTHWESTERN COLORADO

By ROBERT E. BROGDEN, E. CARTER HUTCHINSON, and DONALD E. HILLIER

ABSTRACT

Population growth and the potential development of subsurface mineral resources have increased the need for information on the availability and quality of ground water on the Southern Ute Indian Reservation. The U.S. Geological Survey, in cooperation with the Southern Ute Tribal Council, the Four Corners Regional Planning Commission, and the U.S. Bureau of Indian Affairs, conducted a study during 1974–76 to assess the ground-water resources of the reservation.

Water occurs in aquifers in the Dakota Sandstone, Mancos Shale, Mesaverde Group, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, Kirtland Shale, Animas and San Jose Formations, and terrace and flood-plain deposits. Well yields from sandstone and shale aquifers are small, generally in the range from 1 to 10 gallons per minute with maximum reported yields of 75 gallons per minute. Well yields from terrace deposits generally range from 5 to 10 gallons per minute with maximum yields of 50 gallons per minute. Well yields from flood-plain deposits are as much as 25 gallons per minute but average 10 gallons per minute.

Water quality in aquifers depends in part on rock type. Water from sandstone, terrace, and flood-plain aquifers is predominantly a calcium bicarbonate type, whereas water from shale aquifers is predominantly a sodium bicarbonate type. Water from rocks containing interbeds of coal or carbonaceous shales may be either a calcium or sodium sulfate type. Dissolved-solids concentrations of ground water ranged from 115 to 7,130 milligrams per liter. Water from bedrock aquifers is the most mineralized, while water from terrace and flood-plain aquifers is the least mineralized. In many water samples collected from bedrock, terrace, and flood-plain aquifers, the concentrations of arsenic, chloride, dissolved solids, fluoride, iron, manganese, nitrate, selenium, and sulfate exceeded U.S. Public Health Service (1962) recommended limits for drinking water.

Selenium in the ground water in excess of U.S. Public Health Service (1962) recommended limit of 10 micrograms per liter for drinking water occurs throughout the reservation but principally in the central part. Of the 265 wells and springs sampled, 74 contained water with selenium concentrations in excess of the recommended limit. Selenium concentrations exceeded 10 micrograms per liter principally in water from aquifers in the San Jose and Animas Formations. The maximum selenium concentration determined during the study was 13,000 micrograms per liter in a sample obtained from the San Jose Formation. The only known documented case of human selenium poisoning caused by drinking ground water occurred on the reservation.

INTRODUCTION

This report presents the results of an investigation of the ground-water resources of the Southern Ute Indian Reservation in the southwestern part of Colorado (fig. 1). The 2-year investigation was begun in the spring of 1974 by the U.S. Geological Survey in cooperation with the Southern Ute Tribal Council, the Four Corners Regional Planning Commission, and the U.S. Bureau of Indian Affairs. The reservation is within a region of arid climate. Most of the domestic-water and stock-water supplies are from privately owned wells.

Population growth and the potential development of subsurface mineral resources have increased the need for data on ground-water resources. The purpose of the investigation was to describe the aquifers and the availability and chemical characteristics of ground water in the Southern Ute Indian Reservation. Information derived from this study will aid the Southern Ute Tribal Council in planning future land use and developing water supplies for municipal, industrial, domestic, and stock uses.

The investigation included reviewing published reports and geologic maps, obtaining data from existing wells, drilling test holes, and conducting geophysical surveys in two stream valleys. Water samples were collected from wells, springs, and streams and were analyzed to define the chemical characteristics of surface water and ground water. Geologic information was obtained from published reports by Haynes, Vogel, and Wyant (1972); Steven, Lipman, Hail, Barker, and Luedke (1974); and Shoemaker and Holt (1973).

The authors wish to express their appreciation to Mr. Leonard Burch, Chairman of the Southern Ute Tribal Council, and Mr. Chris A. Baker, Vice Chairman, for providing personnel to assist the U.S. Geological Survey in the collection of basic data. Throughout the investigation, Messrs. Everett Burch, Roderick Williams, Ivan Red, Elliott Cloud, and Raymond Frost helped collect data from wells, under the general guidance of Mr. John Williams who represented the Southern Ute Tribal Council. Their ability to speak English, Ute, and Spanish proved to be of great assistance in discussing the investigation with the many landowners. Messrs. Raymond DeKay and Robert Tsiosdia, and officials and employees of the U.S. Bureau of Indian Affairs, Ignacio, Colo., and Albuquerque and Gallup, N. Mex., provided administrative support during the investigation.

AVAILABILITY OF GROUND WATER

BEDROCK AQUIFERS

Water occurs in sandstone and shale aquifers throughout the Southern Ute Indian Reservation (pl. 1). Sandstone aquifers occur in

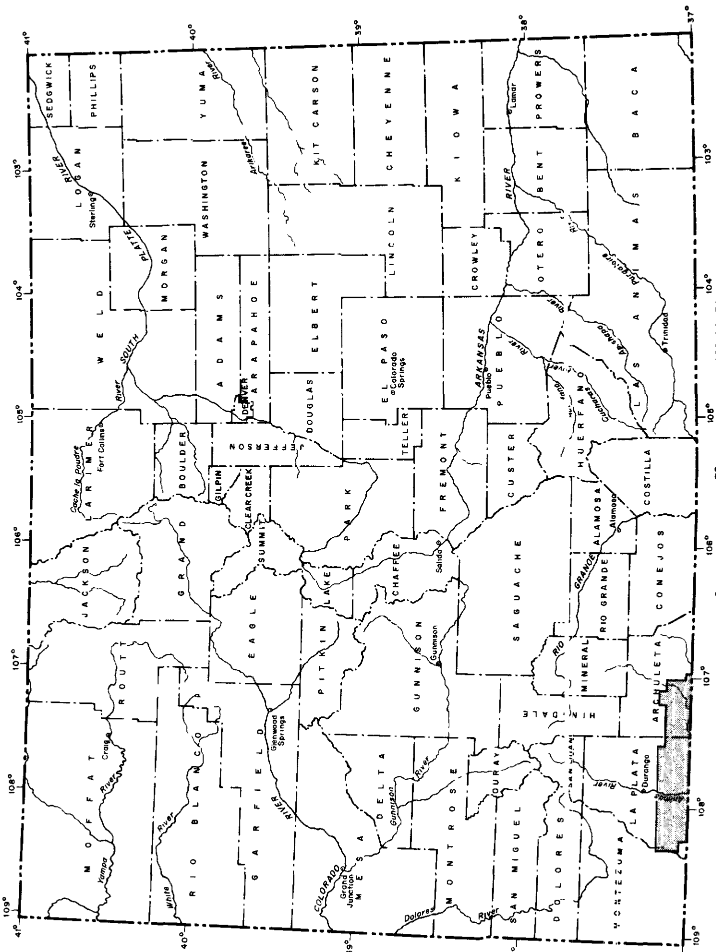

FIGURE 1.—Location of Southern Ute Indian Reservation (shaded).

the Dakota Sandstone, Mancos Shale, Mesaverde Group, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, Kirtland Shale, and Animas and San Jose Formations. The sandstones are all predominantly fine to coarse grained, with varying amounts of calcium carbonate cement which results in small porosity, permeability, and well yields. In the eastern and western parts of the reservation, the Dakota Sandstone, the sandstones in the Mesaverde Group, the Pictured Cliffs Sandstone, and the sandstones in the Kirtland Shale are exposed at the surface. In the central part of the reservation, the Dakota and Pictured Cliffs Sandstones, the three sandstones in the Mesaverde Group, and the sandstones in the Fruitland Formation are overlain by the Animas and San Jose Formations. The sandstone aquifers generally are separated by as much as several hundred feet of shale.

Well yields from the sandstone aquifers generally are less than 10 gal/min. Most of the wells drilled into the Dakota Sandstone, the sandstones in the Mancos Shale, the sandstones in the Mesaverde Group, the sandstones in the Lewis Shale, the Pictured Cliffs Sandstone, the sandstones in the Fruitland Formation, and the sandstones in the Kirtland Shale are reported to yield between 1 and 2 gal/min. Locally, well yields may range from 3 to 5 gal/min. Wells completed in the Animas and San Jose Formations generally yield between 1 and 10 gal/min. The larger yields are reported to be from wells completed in sandstones of the two formations. Maximum reported yields from these aquifers is 75 gal/min.

Artesian wells completed in sandstones that are overlain by impermeable shales occur throughout the reservation. In some parts of the reservation, the hydraulic head in the sandstone aquifers is great enough for water to flow to the surface through cased wells. Yields of flowing wells are small, generally less than 5 gal/min.

Shale aquifers occur principally in the Mancos, Lewis, and Kirtland Shales. Shale aquifers are used for wells when sandstone aquifers are not present. Well yields from shale aquifers generally are less than 1 to 2 gal/min. Well yields are small because shales do not yield water to wells except where fractured.

ALLUVIAL AQUIFERS

Alluvial aquifers consist of terrace and flood-plain deposits. Terrace deposits occur at higher altitudes along the valleys of present-day streams principally in the western one-half of the reservation. Terrace deposits also cap isolated buttes between the major rivers. Flood-plain deposits occur in the valleys of present-day streams (pl. 1). Most of the terrace and flood-plain deposits are composed of sand and gravel derived from erosion of the La Plata Mountains, which are located northwest of the study area. Some of the deposits are derived entirely from local material and consist of fine sands, silts, and clays. Flood-plain deposits are thinnest in the western part of the reservation in the valleys of the La Plata and Animas Rivers. Flood-plain deposits are thickest in the eastern and central parts of the reservation in the valleys of the San Juan, Los Pinos, and Piedra Rivers.

Two large and extensive terraces occur on the reservation (pl. 1). The first, Florida Mesa, is between the Florida and Animas Rivers. The terrace is reported to be as thick as 60 ft but is saturated only in the lower 10 to 20 ft. Wells completed in the aquifer yield a sustained supply of water that ranges from 5 to 10 gal/min. Shale and sandstone of the Animas Formation underlie the terrace. In parts of the Florida Mesa where the saturated terrace deposits are thin, wells have been drilled through the terrace and completed in shale and sandstone. The yields of these wells are generally smaller than wells completed in the terrace deposits.

The second large terrace, located in the western part of the reservation between the towns of Redmesa and Breen in the La Plata River valley, also contains water. This terrace is reported to be 80 to 100 ft thick but saturated only in the lower part. Wells yielding as much as 50 gal/min may be developed in parts of the area where the saturated thickness is greatest, but generally yields are 10 gal/min or less.

Terrace deposits in the river valleys also are saturated in their lower part. Wells completed in these deposits yield a sustained supply of water ranging from 5 to 10 gal/min. Alluvial fans occur on the terrace deposits where they were deposited by intermittent streams flowing into the valleys. Because these deposits are not saturated, wells are drilled through the alluvial fans and completed in the underlying terrace deposits.

Water in the flood-plain deposits is hydraulically connected to water in the streams. Because of this connection, water discharged from the aquifers sustains streamflow during the fall and winter. Withdrawal of water by wells from the flood-plain deposits may reverse the flow of ground water to streams. When this happens, wells completed in the flood-plain deposits of the streams usually will yield a sustained water supply because surface water will move from the stream into the aquifer to replace the withdrawn ground water.

Flood-plain deposits in the La Plata and Animas Rivers are thin, generally less than 10 ft thick (pl. 1). During the drier parts of the year—late summer and fall—water levels in the flood-plain deposits are near the base of the deposits, and in some parts of the valleys the deposits may be almost completely dewatered. Wells that are located within the valleys of the two rivers are often completed in the underlying bedrock aquifers to obtain water from both the bedrock and alluvial aquifers. This procedure usually insures that an adequate supply of water can be pumped. These wells generally yield between 1 and 10 gal/min.

In the Piedra and Los Pinos River valleys and part of the San Juan River valley, wells may be completed entirely in the flood-plain deposits and yield 5 to 25 gal/min, usually an adequate supply for domestic or stock use. Flood-plain deposits in these valleys have a maximum thickness of 50 ft. In the upper reaches of the San Juan River, where the river crosses resistant sandstones, the alluvial deposits are thin and in places are absent. In this part of the reservation, wells are completed in the underlying bedrock aquifers.

SPRINGS

Most of the springs on the reservation occur at hillside exposures where coarse, permeable, saturated materials overlie clay and shale with small permeability. Discharge varies daily and seasonally. Daily fluctuations are due to transpiration by vegetation that grows at the spring site. Discharge is smallest during the day when vegetation is consuming water for growth and is largest at night when demand for water by vegetation is smallest. Perennial springs with a small discharge may be affected greatly by transpiration, whereas springs with large discharges are affected to a lesser degree.

Seasonal fluctuations of spring discharges are related to wet and dry periods of the year. When ground-water recharge from snowmelt and rainfall is large, spring discharge will be large. In the summer and fall, when recharge is small, discharge will be small. During years when rainfall and snowfall are considerably below average, springs may dry up in the summer or fall.

Annual precipitation, aquifer permeability, size and altitude of drainage area, recharge by water used for irrigation, and the presence of faults affect the yield of springs. Spring discharges range from small seeps to as much as 50 gal/min.

Annual precipitation increases with altitude and ranges from about 10 in in the southwestern part of the reservation to more than 25 in in the highlands in the north-central part of the study area. However, most of the reservation receives less than 16 in of annual precipitation. Because most of the annual precipitation occurs in the form of snow, recharge to the aquifers occurs principally from snowmelt in the spring. This results in many springs flowing only during the spring and early summer when recharge is greatest.

The relatively fine grained characteristics of the bedrock results in small discharges of springs issuing from the bedrock aquifers. The largest discharges are from springs flowing from the contact between the more permeable terrace deposits and the less permeable bedrock.

Springs occurring at higher altitudes have relatively small drainage areas and issue from bedrock. Discharges from these springs are small and have large annual and daily fluctuations even though precipitation is significant. These springs usually dry up during the summer and fall. Springs occurring at lower altitudes have relatively large drainage areas, which are underlain in part by permeable terrace deposits. Discharges from these springs are larger and more sustained than discharges from springs at higher altitudes. The discharges of some of these springs may be sustained by recharge of water used for irrigation.

Surface water is used for irrigation on the larger terraces. In some instances, for example the terrace between Redmesa and Breen, seepage from irrigation ditches and infiltration from irrigated fields add enough water to the terrace deposits to induce or sustain springflow. The discharge of springs affected by recharge of irrigation water is not as dependent on annual precipitation as that of springs in nonirrigated areas.

In the eastern part of the reservation there are many faults in the bedrock; springs in this part of the area may be associated with faults. Water moves upwards along the fault planes and is discharged at the land surface. Because of the relatively large amount of water in storage in fractures associated with the faults, discharges from fault-controlled springs generally are not subject to seasonal or annual variations. Water from springs along faults generally is not suitable for drinking and other domestic purposes.

WATER-SUPPLY INVESTIGATIONS FOR CAPOTE LAKE RECREATION AREA AND THE YOUTH CAMP

Alternative water supplies for two recreation areas operated by the Southern Ute Tribal Council were investigated by the U.S. Geological Survey. These investigations were made because the present water supplies are inadequate in both quantity and quality for recreational use.

CAPOTE LAKE RECREATION AREA

Three wells currently (1976) supply water for domestic use in the Capote Lake recreation area located in sec. 10, T. 34 N., R. 4 W. (pl. 1). The wells withdraw water from the Lewis Shale; estimated yields are less than 2 gal/min. On the basis of chemical analyses, the water contained dissolved-solids concentrations in excess of the 500-mg/L (milligrams per liter) limit for drinking water recommended by the U.S. Public Health Service (1962). Dissolved solids ranged from 778 to 1,380 mg/L.

To examine alternative sources of water, several test holes were drilled in the Lewis Shale. Water samples from the test holes contained concentrations of dissolved solids and sulfate greater than the recommended limits for drinking water (U.S. Public Health Service, 1962). Dissolved solids ranged from 1,220 to 1,390 mg/L, and sulfate ranged from 463 to 528 mg/L. Test holes also were drilled in the alluvium of Stollsteimer Creek; however, drilling was abandoned because the auger could not penetrate large boulders in the alluvium.

Other sources of water are Capote Lake and springs in Devil Creek valley. On the basis of chemical analyses, water from both sources contain concentrations of dissolved solids and sulfate in excess of U.S. Public Health Service (1962) recommended limits for drinking water.

One water sample collected from near the surface of Capote Lake contained 883 mg/L dissolved solids and 341 mg/L sulfate. Because water quality in a lake may vary with depth, water samples at the depth of a proposed intake would need to be collected and analyzed to verify the quality of the water that would be piped to the recreation area. If a water supply were developed from the lake, chlorination of the supply would be needed to insure that the water would be free of bacteria. A filtration system also would be needed to remove suspended particles of sediment and organic material usually found in lake water. A storage tank located on a hill west of the lake and a pipeline would be needed to deliver water to the recreation area.

A second alternative for the water supply is to develop one or more of several springs that flow in Devil Creek valley in sec. 8, T. 34 N., R. 4 W., about 2.5 mi west of Capote Lake. The combined yield of the several springs is estimated to be 8 gal/min. Two water samples collected from the springs contained 572 and 716 mg/L dissolved solids and 207 and 269 mg/L sulfate. The altitude of the area of the springs is approximately 6,600 ft above mean sea level. To deliver water from the springs to the recreation area would require a lift of approximately 280 ft to cross a small divide. The water then would flow by gravity through a pipeline from the divide to the recreation area. A storage tank located in the vicinity of the recreation area could provide an adequate water supply. Chlorination of the water supply would be needed to insure that the water would be free of bacteria.

YOUTH CAMP

The youth camp operated by the Southern Ute Tribal Council is located near Devil Creek in sec. 7, T. 34 N., R. 4 W. The present water supply for the camp is from a well completed in the Lewis Shale, reported to be 100 ft deep with an estimated yield of less than 2 gal/min. The yield of this well is inadequate to meet the normal requirements of the camp during the summer, and water frequently must be hauled to the camp during summer sessions. Water from the well contained a dissolved-solids concentration of 820 mg/L and a sulfate concentration of 391 mg/L.

To examine alternative sources of water for the camp, test holes were drilled along Devil Creek near the youth camp to evaluate the saturated thickness of the stream alluvium. As in the instance of the test drilling in the alluvium of Stollsteimer Creek, the auger could not penetrate the entire thickness of alluvium because of large boulders. Two test holes were drilled to a depth of only 5 ft, and a third test hole was drilled to a depth of 17 ft. No water was found in the test holes. However, based on geology and topography, the alluvium along Devil Creek, west of the youth camp, is estimated to be as much as 50 ft thick. Additional test drilling would be required to determine if there is adequate saturated thickness to develop a water supply from wells.

Another possible source for the water supply is the springs in Devil Creek valley about 1 mi east of the youth camp in sec. 8, T. 34 N., R. 4 W., which are the same springs mentioned in the previous discussion of the Capote Lake recreation area. The altitude of the youth camp is about 50 ft lower than that of the springs, and so gravity flow through a pipeline to the youth camp is possible. The pipeline would have to cross Devil Creek. Development of either a well in the alluvium or the springs in Devil Creek valley would require a storage tank and a pipeline to deliver water to the camp.

CHEMICAL CHARACTERISTICS OF GROUND WATER

GENERAL WATER QUALITY

Ground- and surface-water samples were collected from 265 wells and springs and 48 streams and analyzed to identify the chemical characteristics of water on the reservation (Hutchinson and Brogden, 1976). The water samples were analyzed by personnel of the U.S. Geological Survey laboratory, Salt Lake City, Utah, and the U.S. Bureau of Indian Affairs laboratory, Gallup, N. Mex., for major ions, arsenic, and selenium.

Chemical characteristics of ground water in the reservation vary considerably depending on rock type (pl. 1). Water from sandstone aquifers is predominantly a calcium bicarbonate type, whereas water from shale aquifers is predominantly a sodium bicarbonate type. Water from rocks that contain interbeds of coal or carbonaceous shale may be either a calcium or sodium sulfate type. Most of the water in the alluvial aquifers is a calcium bicarbonate type, although sodium bicarbonate and calcium sulfate type waters may be found.

Because of the interbedded and lenticular nature of the bedrock on the reservation, wells penetrating the same aquifer may produce water from different rock types. For this reason, water quality from the same aquifer may vary significantly. This is particularly true for aquifers in the sandstones of the Mesaverde Group and in the Animas and San Jose Formations.

In general, water from the Mancos Shale, Mesaverde Group, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and Kirkland Shale is very mineralized. Water from 45 of the 51 wells and springs sampled contained dissolved-solids concentrations exceeding the U.S. Public Health Service (1962) recommended limit of 500 mg/L for drinking water. Dissolved solids ranged from 222 to 7,130 mg/L. Water from the Animas and San Jose Formations also is very mineralized in a number of wells and springs. Water from 38 of the 100 wells and springs sampled in the Animas Formation contained dissolved-solids concentrations in excess of 500 mg/L. Dissolved solids ranged from 115 to 3,490 mg/L. Water from 34 of the 52 wells and springs sampled in the San Jose Formation contained dissolved-solids concentrations in excess of 500 mg/L. Dissolved solids ranged from 117 to 2,190 mg/L. Locally, water in the bedrock aquifers also contained concentrations of arsenic, chloride, fluoride, iron, manganese, nitrate, selenium, and sulfate in excess of U.S. Public Health Service (1962) recommended limits for drinking water as summarized in table 1.

Water from alluvial aquifers often is not as mineralized as water from bedrock aquifers. Water from 8 of the 28 wells and springs sampled in the terrace deposits contained dissolved-solids concentrations in excess of 500 mg/L. Dissolved solids ranged from 205 to 870 mg/L. Water from 9 of the 34 wells sampled in the flood-plain deposits contained dissolved-solids concentrations in excess of 500 mg/L. Dissolved solids ranged from 148 to 985 mg/L. Concentrations of arsenic, chloride, fluoride, iron, managanese, selenium, and sulfate exceeding the U.S. Public Health Service (1962) recommended limits for drinking water were found in water from some wells and springs in the alluvial aquifers as summarized in table 1.

The quality of water in the flood-plain aquifers is affected by the quality of water recharging the aquifers from streams. Because surface water is generally less mineralized than ground water, the quality of water in the flood-plain aquifers is generally better than that of the bedrock aquifers. Sediment and bacteria, often prevalent in surface water, generally are not found in water from flood-plain aquifers because of the filtration that occurs when the surface water moves through the streambed material and into the ground-water system.

In parts of the reservation, water quality in the alluvial aquifers approximates that of water in the underlying bedrock aquifers. This is because the alluvial material was derived locally from the bedrock, and in parts of the reservation, water is discharged to alluvial aquif-

TABLE 1.—*Occurrence of dissolved constituents exceeding U.S. Public Health Service (1962) recommended limits for drinking water in wells and springs*
[mg/L = milligrams per liter; μg/L = micrograms per liter]

Geologic unit	Total number of wells and springs sampled	Number of wells and springs containing water exceeding limits (shown in parentheses) for indicated constituent								
		Dissolved solids (500 mg/L)	Arsenic (10 μg/L)	Chloride (250 mg/L)	Fluoride (1.3 mg/L)	Iron (300 μg/L)	Manganese (50 μg/L)	Nitrite plus nitrate as N (10 mg/L) or nitrate as NO_3 (10 mg/L)	Selenium (10 μg/L)	Sulfate (250 mg/L)
Flood-plain deposits	34	9	1	0	1	1	2	0	3	4
Terrace deposits	28	8	0	1	1	1	0	0	6	1
San Jose Formation	52	34	5	5	24	4	6	7	27	6
Animas Formation	100	38	11	4	34	5	12	3	33	16
Kirtland Shale	4	4	1	0	0	3	3	0	0	0
Fruitland Formation	2	2	0	0	0	1	1	0	0	1
Pictured Cliffs Sandstone	3	2	0	0	1	0	0	0	0	1
Lewis Shale	20	19	0	2	0	2	0	1	4	13
Mesaverde Group	21	17	0	0	9	4	1	0	0	6
Mancos Shale	1	1	0	0	0	0	0	0	1	1

ers from the underlying bedrock aquifers. This is particularly true of the flood-plain deposits in valleys of streams that originate on the reservation. No wells were found in these valleys, but samples of surface water were collected. The dissolved-solids concentrations of surface water, which reflect the quality of ground water discharged as base flow to streams that originate on the reservation, ranged from 68 to 6,180 mg/L.

WATER-QUALITY PROBLEMS

The discussions of individual constituents that follow are based on information contained in a report by the U.S. Public Health Service (1962). Recommended concentration limits of individual constituents apply only to water used for drinking and domestic use. Limits for other uses are not discussed.

Arsenic.—Ingestion of arsenic may be a potential health hazard. Water with arsenic concentrations exceeding 10 μg/L (micrograms per liter) should not be used for drinking and other domestic purposes. Arsenic ranged from 11* to 61 μg/L in water from 18 wells and springs on the reservation (pl. 1).

Chloride.—Chloride concentrations exceeding 250 mg/L may impart a salty taste to water and to beverages, such as coffee and tea, made using the water. Chloride exceeded 250 mg/L in water from 12 wells on the reservation (pl.1). The maximum chloride concentration determined during the study was 1,700 mg/L.

*Values of 11 or 12 μg/L were determined in two samples. However, because of a possible analytical error of 17 percent, these values may not have exceeded 10 μg/L.

Dissolved solids.—Dissolved-solids concentrations exceeding 500 mg/L may impart an unpleasant taste to the water. Dissolved solids exceeding 5,000 mg/L usually make water completely unusable for drinking. Dissolved solids exceeded 500 mg/L in water from 134 wells and springs on the reservation (pl. 1). The maximum dissolved-solids concentration determined during the study was 7,130 mg/L.

Specific conductance is an indicator of the amount of dissolved minerals in water and therefore, may be used to estimate the dissolved solids. Shown in figure 2 is a graph of specific conductance and dissolved-solids concentrations for more than 250 ground-water samples collected during the study. The dissolved solids from an existing or a new well can be estimated by measuring the specific conductance at the well site, entering figure 2 with the specific-conductance value, and reading the dissolved-solids concentration.

Fluoride.—Based on the annual average of maximum daily air temperatures, the optimum fluoride concentration for drinking water on the reservation is 1.0 mg/L and the upper limit is 1.3 mg/L. Fluoride in drinking water will reduce the rate of tooth decay. When the fluoride concentration is optimum, no ill effects will result and

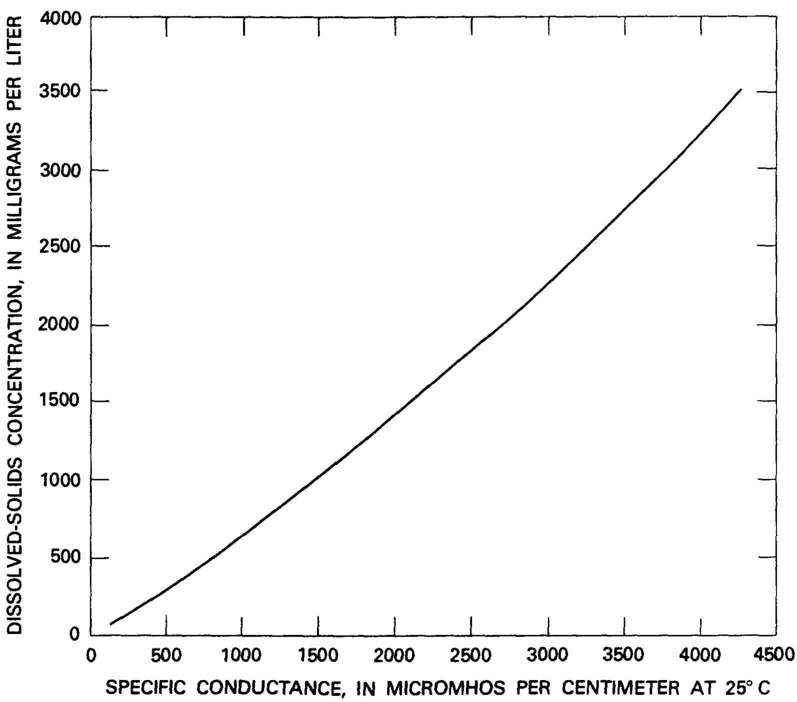

FIGURE 2.—Relation between dissolved-solids concentration and specific conductance.

tooth-decay rates will be 60 to 65 percent less than decay rates where drinking water contains little or no fluoride. Excessive fluoride in drinking water results in discoloring of teeth, especially children's teeth. Fluoride exceeded 1.3 mg/L in water from 70 wells and springs on the reservation (pl. 1). The maximum fluoride concentration determined during the study was 8.8 mg/L.

Iron and manganese.—Iron concentrations exceeding 300 μg/L and manganese concentrations exceeding 50 μg/L impart a bitter taste to beverages, such as coffee and tea, and cause staining of laundry and porcelain fixtures used in kitchens and bathrooms. Iron exceeded 300 μg/L in water from 21 wells and springs on the reservation (pl. 1). The maximum iron concentration determined during the study was 7,700 μg/L. Manganese exceeded 50 μg/L in water from 24 wells and springs on the reservation (pl. 1). The maximum manganese concentration determined during the study was 5,500 μg/L.

Nitrate.—Nitrate concentrations are reported either as nitrite plus nitrate as nitrogen or as dissolved nitrate (Brogden and Hutchinson, 1976). Nitrite plus nitrate as nitrogen in excess of 10 mg/L and dissolved nitrate in excess of 45 mg/L in drinking water may result in serious and occasionally fatal poisoning of infants during their first few months of life. Nitrite plus nitrate as nitrogen exceeded 10 mg/L in water from four wells on the reservation (pl. 1). The maximum nitrite plus nitrate as nitrogen concentration determined during the study was 70 mg/L. Dissolved nitrate exceeded 45 mg/L in water from seven wells on the reservation (pl. 1). The maximum dissolved nitrate concentration determined during the study was 480 mg/L.

The occurrence of nitrate in a water supply is not necessarily related to the aquifer or rock type but may be related to the construction or proximity of the well to septic tanks, barnyards, corrals, or feedlots. Nitrate can be a local problem resulting from improper spacing of a water-supply system with respect to a sewage-disposal system or from contamination by livestock wastes around barns, corrals, and feedlots. Contamination of a water supply also can result from overapplication of fertilizers.

Sulfate.—Sulfate concentrations exceeding 250 mg/L may impart a bitter taste to the water and may have a laxative effect, especially to newcomers to the area or occasional users of the water. Usually the laxative effect disappears in a relatively short time with continued use of the water. Sulfate exceeded 250 mg/L in water from 49 wells and springs on the reservation (pl. 1). The maximum sulfate concentration determined during the study was 4,050 mg/L.

Selenium.—Ingestion of selenium may be a potential health hazard. Water with selenium concentrations exceeding 10 μg/L should not be used for drinking and other domestic purposes.

Selenium exceeded 10* μg/L in water from 74 of the 265 wells and springs sampled (pl. 1). The maximum selenium concentration determined during the study was 13,000 μg/L.

Whereas minor amounts of selenium are required for normal growth and maintenance of life, the ingestion of selenium in excess of the 10-μg/L limit may result in selenium poisoning. Selenium poisoning in humans is characterized by nervousness, vomiting, cough, convulsions, abdominal pain, diarrhea, hypertension, and respiratory failure (U.S. Environmental Protection Agency, 1973). At the present time, few data are available to determine what concentration of selenium in drinking water will cause selenium poisoning.

Animals, particularly cattle and sheep, also are subject to selenium poisoning and have died from acute selenium poisoning. The so-called "alkali disease" and "blind staggers" that afflict cattle and sheep are caused by selenium poisoning.

Selenium occurs in plants and dust as well as water. Plants, including vegetables and grains, grown on soils rich in selenium can absorb the element and dust also can contain selenium minerals. Eating selenium-rich vegetables and grains and inhaling dust particles can introduce selenium into a person's or animal's system.

GENERAL OCCURRENCE OF SELENIUM ON THE RESERVATION

Selenium concentrations exceeding 10 μg/L occur locally in water in the Mancos Shale, Lewis Shale, Animas Formation, San Jose Formation, terrace deposits, and flood-plain deposits. Water from the one well completed in the Mancos Shale contained 12 μg/L selenium. Four wells completed in the Lewis Shale contained selenium in concentrations of 11, 16, 20, and 52 μg/L.

As much as 450 μg/L selenium has been determined in water in the Animas Formation. Selenium exceeded 10 μg/L in water from 33 of the 100 wells sampled and was greater than 100 μg/L in 3 wells. Wells containing water with selenium exceeding 10 μg/L are found throughout the reservation (pl. 1).

As much as 13,000 μg/L selenium has been determined in water in the San Jose Formation. The occurrence of selenium in water in the San Jose Formation appears to be concentrated in two areas in the central part of the reservation, rather than being widely distributed as in the Animas Formation. One area where selenium in water ranged from less than 10 to 13,000 μg/L is approximately bounded by

*Values of 11 or 12 μg/L were determined in six samples. However, because of a possible analytical error of 17 percent, these values may not have exceeded 10 μg/L.

the Durango-La Plata County Airport on the west, the community of Oxford on the north, and the community of Ignacio on the south and east (pl. 1). The second area where selenium ranged from 7 to 220 μg/L is in the vicinity of the community of Arbolese, which is located on the northwest shore of the Navajo Reservoir.

As much as 310 μg/L selenium also was found to occur in water in the alluvial aquifers along the Animas River. The selenium in the alluvial aquifers probably is due to either (1) ground-water inflow from aquifers in the San Jose and Animas Formations to the alluvial aquifers or (2) infiltration of surface runoff that has flowed over the San Jose and Animas Formations. Parts of the aquifers in the flood-plain and terrace deposits along the Animas River are composed of material eroded from the San Jose and Animas Formations. It is possible that selenium minerals present in this material are dissolved by water infiltrating through the material, resulting in increased selenium concentrations in the water.

OCCURRENCE OF SELENIUM, OXFORD TRACT

The Oxford Tract is an area of approximately 3 mi^2 in T. 34 N., R. 8 W. (pl. 1 and fig. 3). Selenium occurs in the soils, in the sandstones and shales to a depth of at least 500 ft, in streams, in the ground water, and in plants. Rock units on the tract are the interbedded, fine-grained, silty sandstones and shales of the San Jose Formation. Ground water occurs throughout the Oxford Tract in both the sandstones and the shales. Plants that concentrate selenium in their tissue are common on the tract. These plants include the milkvetch, woody aster, goldenweed, princesplume, gumweed, and the snakeweed. Gumweed is the most abundant plant in the area and grows under drought conditions when most other vegetation types are burned to root level.

It is in this part of the reservation that the only known case of human selenium poisoning was documented and described by Beath (1962). Selenium poisoning of livestock has been reported throughout the reservation, but these cases have not been documented by local officials or by the U.S. Bureau of Indian Affairs.

The documented case of human selenium poisoning mentioned above involved the Kaare Evensen family. Symptoms of the poisoning lasted the entire period of time that the family lived within the tract but disappeared when the family moved. Domestic water used by the family was from a well that was drilled to a depth of about 140 ft. Analysis of a water sample collected from the Evensen well in 1962 indicated that the selenium concentration in the drinking water was 9,000 μg/L (Beath, 1962). Two water samples were collected from the domestic well during this study. Analyses of the samples indicated

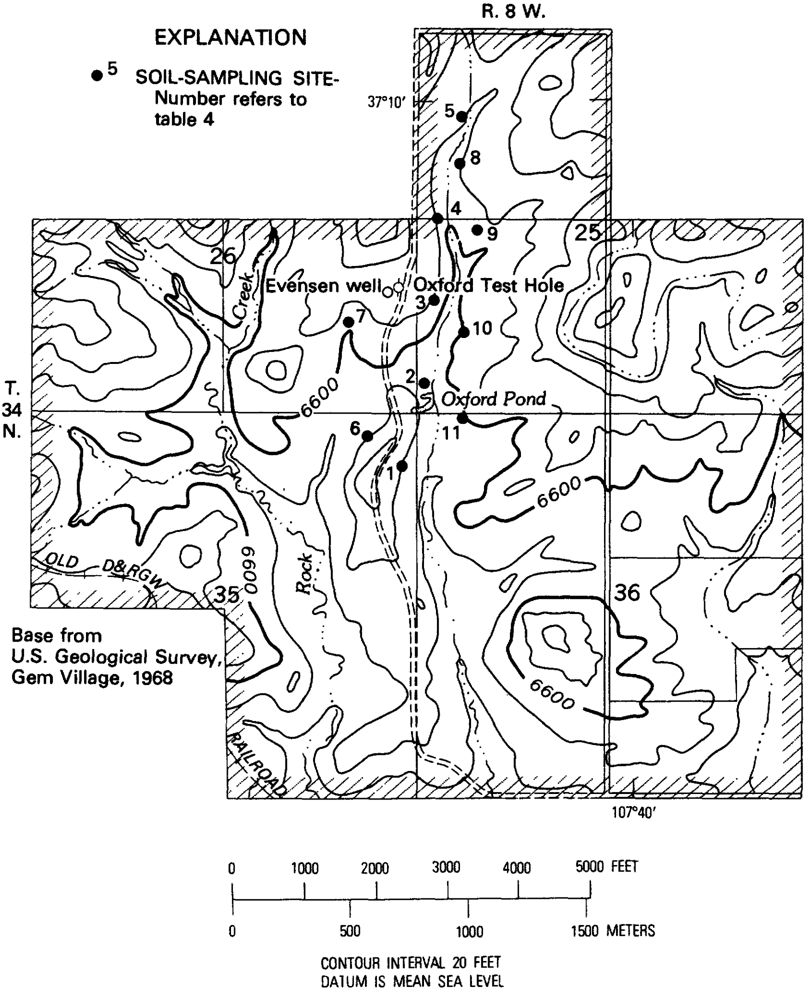

FIGURE 3.—Location of soil-sampling sites and wells on the Oxford Tract.

that selenium concentrations were 33 and 58 μg/L, a 150-fold decrease from the selenium determined in 1962.

To determine the occurrence of selenium in the ground water and in the shales and sandstones of the San Jose Formation, the U.S. Geological Survey drilled a test hole approximately 85 ft east of the Evensen domestic well. The geologic log of the test hole is in table 2. The water level in the test hole was measured at 35 ft below the land surface. The content of selenium found in the shales and fine-grained, silty sandstones is shown in table 3. Selenium content in the rocks ranged from less than 0.1 ppm (part per million) at a depth of 2 ft to as much as 3.6 ppm at a depth of 42 ft. Selenium content in the rocks is less than 0.4 ppm at depths ranging from 2 to 27 ft and is generally greater than 0.4 ppm at depths ranging from 27 to 500 ft.

Six water samples were collected from the test hole during the drilling and after the test hole was completed to determine selenium concentrations. The data are summarized in the table below:

Date of sample	Selenium concentration, in micrograms per liter	Remarks
July 29, 1975	400	Sampled during drilling, first water-bearing zone penetrated, depth 35 ft.
July 30, 1975	540	Sampled during drilling, second water-bearing zone penetrated, depth 122 to 132 ft.
August 26, 1975	120	Well completed, water level at 20 ft. Sample taken at 60 ft.
August 27, 1975	330	Pumping, water level drawn down to 125 ft, recovered to 122 ft where sample taken.
October 2, 1975	260	Pumping, water level drawn down to 118 ft, recovered to 113 ft. Sample taken at 115 ft.
October 26, 1975	90	Water level at 17 ft. Sample taken at 45 ft.

During the drilling, a similarity was found between the selenium content of the rocks (0.4 ppm) and the concentration of selenium in water (400 μg/L) entering the test hole at a depth of 35 ft. After the second water-producing zone was penetrated at a depth between 122 and 132 ft, the selenium in the water, which was a composite from the two producing zones, increased to 540 μg/L. The selenium content in the rock at the depth of the second producing zone (122 to 132 ft) probably is greater than the 0.4 ppm determined at a depth of 125 ft (table 3), and the water entering the test hole from the deeper producing zone must have a correspondingly larger selenium concentration to account for the increase in selenium concentration.

The reason for the decreases in the selenium concentrations after completion of the test hole is not known. A possible explanation is that selenium, probably as selenite, adheres to precipitating materials, such as hydrated iron oxides, thereby resulting in smaller dissolved concentrations (Howard, 1972). Pumping causes water with larger selenium concentrations to move into the test hole from the aquifers. Cessation of pumping is then followed by a period of precipitation.

Water samples also were collected from an irrigation ditch that crosses the tract and from a small pond adjacent to the tract. The selenium concentration of water from both the irrigation ditch and the small pond was less than 10 μg/L.

TABLE 2.—*Geologic drill-hole log, Oxford Tract test hole*

Location.—Lat 37°09′34″N, long 107°40′ 41″ W., in sec. 26DAD, T. 34 N., R. 8 W., N.M.P.M., Southern Ute Indian Reservation, La Plata County, Colo. Collar elevation 6,635 ft, total depth 507 ft. Date: July 28 through August 2, 1975.

Remarks.—Hole bottomed at 507 ft following caving after flushing about 1 hour. Initial 9-in hole to 21 ft. Set 8⅝-in steel casing and cemented. Seven-inch hole 21 to 507 ft. Set 6-in plastic casing at 502 ft. Two joints of 20-ft length perforated and set at 24 to 44 ft and 104 to 124 ft. Steel casing at surface 1.0 ft above land surface. Welded cap, hinged, and padlocked.

Depth (feet)		San Jose Formation		Log
From	To	Thickness (feet)	Rock	
0	10	10	Weathered shale	Topsoil and weathered green to gray silty shale.
10	28	18	Shale, siltstone	Shale and siltstone, gray and maroon, interbedded.
28	35	7	Shale	Interbedded gray and dull-green shale layers, silty. Encountered water at 35 ft; measured yield ⅛ gal/min. Sampled for chemical analysis.
35	90	55	Shale and siltstone.	Interbedded gray and green shale with siltstone. Silty layers at 42 to 48 ft and 60 to 73 ft. Maroon shale from 72 to 75 ft and 83 to 90 ft; fine-grained sandstone layers 80 to 82 ft.
90	155	65	do.	Interbedded gray and dull-green layers, interbedded with maroon shale. Sandstone and siltstone beds at 100 to 105 ft and 122 to 132 ft. Maroon beds at 150 to 155 ft. Small gain in water at 122 to 132 ft. Yield less than ⅛ gal/min. Sampled for chemical analysis.
155	305	150	do.	Siltstone, sandstone, and shale, interbedded, gray to dark-gray and thin maroon layers. Maroon shale 165 to 172 ft, 187 to 190 ft, 238 to 248 ft, and 268 to 273 ft. Silty sandstone lenses 202 to 205 ft, 222 to 225 ft, and 275 to 295 ft. Drill cuttings platy, hard to drill.
305	320	15	Shale	Maroon, silty shale, hard to drill.
320	365	45	do.	Gray, silty shale, sandstone lenses at 340 to 350 ft, thickness varies from 3 to 10 ft, hard.
365	383	18	Siltstone	Interbedded siltstone and silty maroon shale, platy cuttings.
383	403	20	Shale	Gray, silty shale, some soft lenses. Lost circulation at 400 to 403 ft; electric logs indicated cavity of about 2-in diameter.
403	417	14	Siltstone, sandstone.	Gray siltstone and hard sandstone, hard to drill.
417	470	53	Shale	Silty gray and maroon layers, interbeded. Maroon layers at 417 to 420 ft, siltstone layers at 430, 458, and 465 ft. Hard to drill, platy cuttings.
470	507	37	Sandstone	Silty sandstone, some siltstone, with thin layers of maroon shale at 480, 490, and 500 ft. Sandstone near bottom very fine grained and moderately hard.

During a reconnaissance investigation of the Oxford Tract, the U.S. Bureau of Indian Affairs drilled 11 test holes, 48 in deep, throughout the tract (fig. 3). Soil samples from the test holes were analyzed for their selenium content (table 4). Selenium content ranged from 0.1 to 6 ppm in the zone from land surface to a depth of 10 in. In 8 of the 11 soil-test sites, the selenium content in the soils increased with depth. At sites 2 and 6 the selenium content was less at the base of the test holes than at the top; at site 10 the selenium content was the same both at the bottom and top of the test hole. The U.S. Bureau of Indian Affairs also analyzed water samples collected from the pond near the tract and tissue from a fish from the pond. The selenium concentration was a trace in the pond water and 3.0 ppm in the fish. A second test by the U.S. Bureau of Indian Affairs of the same pond water and fish tissue indicated that the water contained a trace of selenium and that the fish contained 0.49 ppm selenium.

TABLE 3.—*Selenium content in rocks, Oxford Tract test hole*
[Analyzed by U.S. Geological Survey]

Depth below land surface (feet)	Selenium content (parts per million)	Depth below land surface (feet)	Selenium content (parts per million)
2	<0.1	40	0.6
5	<.1	42	3.6
7	<.1	45	.7
10	<.1	47	.6
12	.2	50	1.8
15	<.1	75	.5
17	.2	100	1.6
20	.2	125	.4
22	<.1	150	.1
25	.1	200	.8
27	.4	250	.8
30	.9	300	1.2
32	.4	350	.2
35	.4	400	.6
37	.6	450	.4
		500	.5

TABLE 4.—*Selenium content in soil samples, Oxford Tract*
[Collected and analyzed by U.S. Bureau of Indian Affairs]

Soil-sample location number[1]	Selenium content, in parts per million			
Depth below land surface, in inches	0–10	10–20	20–36	36–48
1	0.1	0.2	0.2	0.2
2	.2	.1	6.0	.14
3	.2	.2	1.4	10.0
4	.2	.2	1.4	1.4
5	1.0	4.0	4.0	10.0
6	6.0	trace	1.0	.2
7	.2	.2	1.0	1.0
8	.2	.2	1.0	1.4
9	.1	.1	.2	.2
10	.2	.1	.2	.2
11	.1	.1	.1	.2

[1]Soil-sample location numbers are shown on figure 3.

OCCURRENCE OF SELENIUM, HARMON RANCH

The Harmon Ranch is approximately 5 mi southwest of the Oxford Tract. Two wells and one seismograph exploration hole that was left open for use as a water well are located on the ranch. Four water samples collected from the Harmon Ranch wells indicated large differences in selenium concentrations in the water. The first sample collected from well 1 on June 18, 1974, contained 7,860 μg/L selenium. The second sample collected from well 1 on July 24, 1975, contained 13,000 μg/L selenium. The third sample collected from well

2 on October 1, 1975, contained 5,400 μg/L selenium. A water sample collected from the seismograph exploration hole on October 1, 1975, contained 6,200 μg/L selenium.

Currently (1976), all drinking water and water used for culinary purposes on the Harmon Ranch is being hauled by tank truck. Water from one well is still being used for domestic cleaning and washing purposes. Water for irrigation of the lawn, shrubs, trees, and garden is supplied by a storage system developed to trap rain and snowmelt.

DISCUSSION CONCERNING SELENIUM CONCENTRATIONS

Because there is little information that describes the mobility of selenium in a ground-water environment, it is difficult to draw quantitative conclusions concerning the occurrence of selenium in ground water. However, some generalizations describing the occurrence of selenium on the reservation can be made.

1. Selenium concentrations in water are largest in formations that contain volcanic rocks. The San Jose and Animas Formations both contain fragments of andesite and rhyolite, both of which are of volcanic origin.

2. Selenium concentrations in water generally are largest when arsenic concentrations are smallest; the reverse is also true. Selenium in concentrations exceeding 10 μg/L occurs in water from 74 wells and springs, and arsenic in concentrations exceeding 10 μg/L occurs in water from 18 wells and springs. However, only water from three wells and one spring in the Animas Formation and one well in the San Jose Formation contained both selenium and arsenic in concentrations exceeding 10 μg/L.

3. The occurrence of selenium in ground water is variable even within a region containing water with large selenium concentrations. There are several wells inside of and close to both the Oxford Tract and the town of Arbolese that yield water containing selenium concentrations less than 10 μg/L. No apparent pattern was established that describes the variation in the concentration of selenium.

4. Selenium occurs in both shallow and deep aquifers. Water samples collected from wells as shallow as 10 ft contain selenium concentrations in excess of 10 μg/L, as does water from flowing wells as deep as 300 ft.

5. Rocks rich in seleniferous minerals undoubtedly account for a part of the selenium concentrations in the water. Another source of selenium in the water could result from the decomposition of selenium-accumulating plants, such as the gumweed and others, all of which are common on the Oxford Tract. These plants can concentrate as much as 1,400 ppm selenium in their tissue (U.S. Bureau of Indian Affairs, written commun., 1971). The decay of dead plants in

the soil zone, the buildup of selenium in the soil, and leaching of the soluble selenium in the decayed material by infiltrating water could contribute to the selenium in the ground water and to large selenium concentrations in the upper soil zone throughout the Oxford Tract. This is indicated from soil samples analyzed by the U.S. Bureau of Indian Affairs (table 3), although more drilling and sampling of rock in a detailed investigation would be required to support this conclusion.

DEVELOPMENT OF GROUND-WATER SUPPLIES

No wells capable of yielding more than 75 gal/min are known to exist within the boundaries of the reservation. However, it may be possible to construct wells yielding more than 75 gal/min in the valleys of the Piedra, Los Pinos, and San Juan Rivers where the flood-plain deposits may be as thick as 50 ft. Wells with sustained yields of more than 75 gal/min probably cannot be obtained from terrace and bedrock aquifers. Because the demand for ground water will not be limited to the valleys of perennial streams where larger yielding wells may be developed, proper well construction and development of permanent springs in other areas will be needed to obtain maximum yields for domestic and stock purposes. The following sections describe some techniques that landowners may use to obtain adequate supplies of water from wells and permanent springs.

CONSTRUCTION OF WELLS AND INFILTRATION GALLERIES

Most of the wells drilled on the reservation are shallow and penetrate only the upper part of an aquifer. Wells that do not penetrate the entire thickness of an aquifer may not be able to pump water during extreme or extended droughts. During dry years, the water level in the aquifer can decline to such an extent that the water level may be below the bottom of the well.

Drilling wells to the base of an aquifer will, in most situations, insure an adequate supply of water for domestic or stock purposes. In the alluvial aquifers, wells drilled through the sand and gravel and into the underlying shale or sandstone formations will generally yield water even when the streams go dry. In the sandstone aquifers, wells completed through the entire section of a sandstone will yield more water with less drawdown than a well completed only in the upper part of the sandstone. Wells in the shale aquifers may be drilled deeper than the base of the fractured zone. This is often done when the aquifer has extremely small water-transmitting capabilities. The deeper hole provides well-bore storage which allows the pump to withdraw water for a limited time at a greater rate than water enters the well from the aquifer.

Domestic or stock use requires very little water and, if the well and distribution system are constructed properly, the pump needs to be used only a small part of the day. Wells with casings 4 to 6 in in diameter are adequate for meeting normal stock or domestic requirements. Maximum yields from alluvial aquifers are generally achieved from wells that penetrate the full thickness of alluvial material and that are open opposite the total thickness of saturated material. Maximum yields from sandstones with water under artesian conditions are generally achieved from wells that are open to the full thickness of the sandstone.

Openings to the aquifer in cased wells may consist of torch slots, saw perforations, or well screens. For wells drilled in the alluvial aquifers, a gravel pack between the casing and the aquifer is generally effective in keeping silt or fine sand from being pumped into the water-distribution system and at the same time allowing water to flow easily into the well. Gravel packs may be needed for wells completed in sandstone and shale aquifers, also.

Infiltration or collection galleries are alternatives to wells for the development of water supplies. These structures have the greatest application in parts of the reservation where aquifers are thin and near the surface. Infiltration or collection galleries are virtually horizontal wells and consist of slotted or perforated pipe or drainage tiles which extend laterally into an aquifer and allow water to move by gravity to a central collection point equipped with a pump. Locations favorable for the construction of infiltration galleries are the alluvial valleys of the Piedra, Los Pinos, and Animas Rivers, and in the terrace deposits that occur in the valleys.

Construction of either wells or infiltration galleries at least 100 ft upslope from septic tanks, corrals, or barnyards may prevent the contamination of a water supply. The State of Colorado (Colorado Division of Water Resources, 1972) has established the following minimum standards for locating wells near sources of contamination:

> Wells producing water for human consumption and/or food processing shall be located no closer than 100 feet from the nearest potential sources of contamination, such distance being measured from the nearest potential source of contamination to a point of juncture with the well casing and the top of the aquifer.
>
> Provided further, that the horizontal distances between the well casing and the potential source of contamination shall be 25 feet or more and the casing be grouted from that point to the top of the aquifer.

The above regulations are shown schematically on figure 4.

Cementing or grouting the well at the surface to prevent surface runoff from entering the well will reduce the possibility of contamination of the water supply. Grouting of wells is required by the State of Colorado (Colorado Division of Water Resources, 1972). Regulations governing grouting are summarized in table 5.

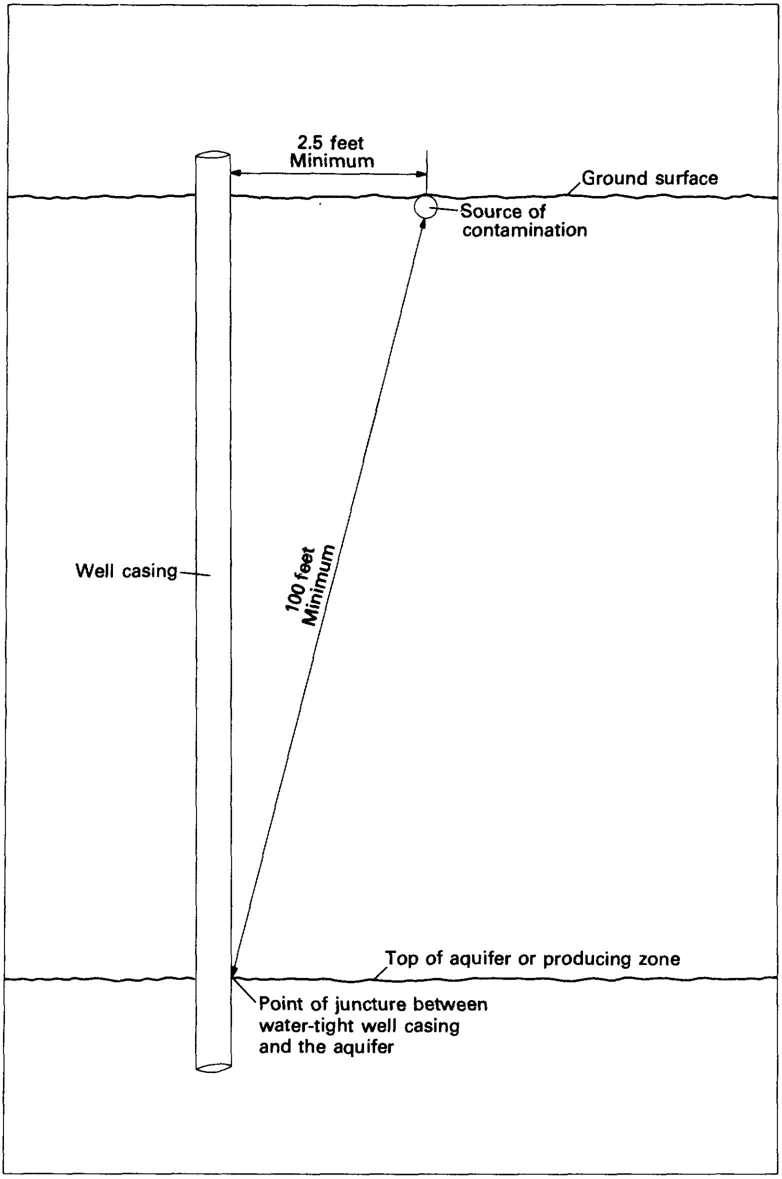

FIGURE 4.—Minimum distances that wells are to be constructed from sources of contamination. (Adapted from Colorado Division of Water Resources, 1972.)

DEVELOPMENT OF PERENNIAL SPRINGS

The development of perennial springs can often insure an adequate domestic or stock supply of water. Springs are developed by removing vegetation from around the point of discharge and installing slotted

TABLE 5.—*Summary of State of Colorado's well construction and grouting regulations*
[Adapted from Colorado Division of Water Resources, 1972, section 4 and table 1]

Water-bearing formation	Overburden	Minimum grouting depth[1]	Minimum casing depth[2] (water tight)
Sand, gravel, or decomposed igneous rock.	Unconsolidated material, clay, shale, sand, etc.	10 ft to surface	5 ft below pumping water level.
Confined aquifers (Dakota Sandstone, Morrison Formation, Fox Hills Sandstone, Dawson Formation, etc.).	Mixed deposits of clay, shale, sand, and gravel.	10 ft to surface and grouted 10 ft into an impervious formation.	Top of production zone.
Creviced, shattered, or fractured hard rock.	Unconsolidated material.	10 ft to surface	Top of production zone.
Creviced, shattered, or fractured hard rock.	Consolidated rock.	20 ft to surface	20 ft.

[1]Confined waters shall be separated from each other and from unconfined waters encountered in the same hole by grouting with cement, concrete, or other approved materials.
[2]All wells producing water for human consumption or food processing shall have watertight casing from the surface of the ground to the top of the producing zone of the aquifer unless otherwise authorized by table 1. In no event shall said watertight casing be less than 10 feet below the ground level.

or perforated pipe or drainage tile horizontally into the aquifer. A tank, located downslope from the spring, is used to store the water for domestic or livestock use.

OTHER CONSIDERATIONS

Development of separate water supplies for domestic, stock, and garden irrigation is a possibility because of varying tolerances of humans, livestock, and plants to minerals in water. Development would be based on an adequate supply of water being available to meet the separate needs. Water that is not potable for humans could, in many instances, be used for watering livestock and gardens. This would allow potable water to be used exclusively for domestic purposes.

Mixing potable water with nonpotable water is a way to increase the total amount of potable water available for consumption. Chemical analyses of both types of water are needed to determine the proportion of each type that would need to be mixed to obtain the larger potable supply.

Corrosion of steel well-casing perforations and encrustation of steel or plastic well-casing perforations can affect both the water supply and the water quality. Corrosion, the removal of metal from the openings, and encrustation, the deposition of minerals on the openings, is dependent on the quality of the water moving into a well. Examination of a chemical analysis will determine whether the water is of the corrosion or the encrustation type and will allow the well owner and well driller to design the well accordingly.

Generally, water will cause corrosion if any of the following factors occur in combination: The pH is less than 7.0, dissolved-oxygen concentration exceeds 2 mg/L, hydrogen sulfide is detected by odor or taste, dissolved-solids concentration exceeds 1,000 mg/L or specific conductance is greater than 1,400 μmhos/cm, carbon dioxide concentration exceeds 50 mg/L, or chloride concentration exceeds 500 mg/L.

Generally, water will cause encrustations if any of the following occur in combination: The pH exceeds 7.5, carbonate-hardness concentration exceeds 300 mg/L, or manganese concentration exceeds 1 mg/L.

If the chemical analysis indicates that the water is corrosive, installation of a steel well casing with smaller perforations or slots, and a thicker and stronger wall will increase the time before replacement of the casing is needed. Stainless-steel casings and screens are corrosion resistant. Using stainless steel will not prevent corrosion from taking place but will delay the need for replacing the well casing and screen. Plastic well casing is virtually uncorrodible.

If the chemical analysis indicates that the water may be encrustating, the use of somewhat larger openings than actually required will increase the time before replacement of the casing is needed. With time, the well-casing openings will close as minerals are deposited about the perforations. Periodic treatment of the well screen with hydrochloric acid or solid carbon dioxide will dissolve and remove the mineral deposits. However, the acid treatment is corrosive and the well needs to be designed to withstand the effects of the treatment. Encrustations also may be removed by surging or backwashing the well.

In many instances, severe corrosion of steel casings will increase iron concentration to the point that staining of laundry and fixtures will occur. Corrosion also dissolves other trace metals from the casing. However, the resulting concentrations of the trace metals in the water are generally so small that they do not affect the use of the water.

The principal effect of well-casing encrustation on water quality is not related to the encrustations themselves but rather is related to the removal of the encrustations by hydrochloric acid. After treatment with hydrochloric acid, the well needs to be pumped for a period to allow all the hydrochloric acid to be removed from the well and water-distribution system.

SUMMARY

Ground water may be found throughout the reservation in sandstone, shale, and sand and gravel aquifers. Well yields from aquifers in the sandstones and shales are small and range from 1 to 10 gal/min.

Aquifers that yield as much as 50 gal/min are found in saturated terrace deposits between the towns of Redmesa and Breen in the La Plata River valley. Well yields ranging from 5 to 10 gal/min can be obtained from terrace deposits underlying Florida Mesa, which is located between the Florida and Animas Rivers. Terrace deposits in the river valleys yield a sustained supply of water ranging from 5 to 10 gal/min.

Aquifers that yield as much as 25 gal/min are found in the flood-plain deposits of the streams. In the western part of the reservation, aquifers in the La Plata and Animas River valleys are thin, generally less than 10 ft thick, and sometimes absent, but in the eastern part of the reservation, flood-plain deposits in the valleys of the San Juan, Los Pinos, and Piedra Rivers have a maximum thickness of 50 ft. Ground water in the flood-plain deposits is hydraulically connected to water in the streams. Because of the hydraulic connection between ground water and surface water, water discharged from the deposits sustains streamflow during the drier months of fall and winter. Withdrawal of water by wells from the flood-plain deposits can reverse the flow of ground water, causing water from streams to move into the deposits to the wells. A sustained water supply usually results because of this induced recharge.

Springs occur throughout the reservation principally at the contact between coarse, permeable materials that overlie relatively impermeable clays and shales. The discharge of the springs varies both daily and seasonally. Daily fluctuations are caused by transpiration of vegetation and seasonal fluctuations are caused primarily by variation in monthly and annual precipitation. The quality of water from these springs is variable. In the eastern part of the reservation, springs may occur along faults where water moves upwards along the fault planes and is discharged at the land surface. The discharge of these springs generally is not subject to seasonal or annual variations because of the large amount of water in storage in fractures associated with the faults. The quality of water from springs on faults generally is not suitable for drinking.

Water quality in aquifers depends in part on rock type. Water from sandstone and alluvial aquifers is predominantly a calcium bicarbonate type, whereas water from shale aquifers is predominantly a sodium bicarbonate type. Water from rocks containing interbeds of

coal or carbonaceous shales may be a calcium or sodium sulfate type.

Because of the interbedded and lenticular nature of the bedrock on the reservation, wells completed in the same aquifer may produce water from different rock types. For this reason, water quality within the same aquifer may vary significantly. This is particularly true for aquifers in the sandstones of the Mesaverde Group and in the Animas and San Jose Formations. In general, water from bedrock aquifers is more mineralized than water from alluvial aquifers. Water from the Mancos Shale, Mesaverde Group, Lewis Shale, Pictured Cliff Sandstone, Fruitland Formation, and Kirkland Shale contained dissolved-solid concentrations ranging from 222 to 7,130 mg/L. Water from aquifers in the Animas and San Jose Formations contained 115 to 3,490 mg/L dissolved solids. Water from alluvial aquifers contained 148 to 485 mg/L dissolved solids. In many water samples, collected from both bedrock, terrace, and flood-plain aquifers, concentrations of arsenic, chloride, dissolved solids, fluoride, iron, manganese, nitrate, selenium, and sulfate exceeded the U.S. Public Health Service (1962) recommended limits for drinking water.

The only known documented case of human selenium poisoning caused by drinking ground water occurred on the reservation. The drinking water used by the Kaare Evenson family contained 9,000 μg/L selenium, a concentration greatly in excess of the 10-μg/L limit for drinking water recommended by the U.S. Public Health Service (1962). Selenium was found to occur in excess of 10 μg/L in water from 74 of the 265 wells and springs that were sampled during the investigation. Large selenium concentrations, as much as 13,000 μg/L, were determined in water from the San Jose Formation. Selenium also was found to be prevalent in water from the Animas Formation; the maximum concentration determined was 450 μg/L. Occurrence of selenium in water from the Animas Formation is more variable and intermittent than the occurrence of selenium in water from the San Jose Formation.

Information that described the mobility of selenium in the ground-water environment was not developed during the study, but some generalizations can be made that describe the occurrence of selenium in ground water on the reservation.

1. Selenium concentrations in water are largest in formations that contain fragments of volcanic material. Both the San Jose and Animas Formations contain fragments of andesite and rhyolite that are volcanic in origin.
2. Selenium concentrations in water are largest when arsenic concentrations are smallest; the reverse also is true.
3. The occurrence of selenium in ground water is variable even

within a region containing water with large selenium concentrations.

4. Selenium occurs in both shallow and deep aquifers. Selenium was found in excess of 10 μg/L in water from wells as shallow as 10 ft and as deep as 300 ft.

5. Rocks rich in seleniferous minerals undoubtedly account for a part of the selenium concentrations in the water. Another source of selenium could result form the decay of selenium-accumulating plants that grow on the reservation. The decay of dead plants in the soil zone, the buildup of selenium in the soil, and leaching of the soluble selenium in the decayed material by infiltrating water could contribute to the selenium in the ground water and to the presence of large quantities of selenium in the upper soil zone.

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